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DCPA ATTACK ENVIRONMENT MANUAL

CHAPTER 3

WHAT THE PLANNER NEEDS TO KNOW ABOUT FIRE IGNITION AND SPREAD

DEFENSE CIVIL PREPAREDNESS AGENCY
DEPARTMENT OF DEFENSE

JUNE 1973

DCPA ATTACK ENVIRONMENT MANUAL

WHAT THE EMERGENCY PLANNER NEEDS TO KNOW ABOUT THE NATURE OF NUCLEAR WAR

No one has gone through a nuclear war. This means there aren't any natural experts. But civil defense officials are in the business of preparing against the possibility of nuclear war. Intelligent preparations should be based on a good understanding of the operating conditions that may occur in a war that has never occurred. Lacking such understanding, emergency operating plans probably won't make much sense if they have to be used.

This manual has been prepared to help the emergency planner understand what the next war may be like. It contains information gathered from two decades of study of the effects of nuclear weapons and the feasibility of civil defense actions, numerous operational studies and exercises, nuclear test experience, and limited experience in wartime and peacetime disasters that approximate some of the operating situations that may be experienced in a nuclear attack. In short, it summarizes what the Defense Civil Preparedness Agency now knows about the nuclear attack environment as it may affect operational readiness at the local level.

LIST OF CHAPTER TITLES

PREFACE TO CHAPTER 3

This description of the fire environment following nuclear attack is intended to provide the operational planner with the basic information needed to plan realistic fire defense actions. It presumes that the reader is familiar with the material in Chapters 1 and 2 of the Manual. Knowlege of the material in subsequent chapters is not necessary.

Information is presented in the form of "panels," each consisting of a page of text and an associated sketch, photograph, chart, or other visual image. Each panel covers a topic. This preface is like a panel with the list of topics in Chapter 3 shown opposite. If the graphic portion is converted into slides or vugraphs, the chapter or any part can be used in an illustrated lecture or briefing, should that be desired.

The ordering of topics begins with one introductory panel, followed by three on the thermal hazards to people. There are five panels on ignitions and initial fires. Five subsequent panels discuss the impossibility of firestorms in nuclear attack. There follow ten panels on the dynamics of fire growth and spread. Six panels describe life safety in the fire environment and one deals with damage to property. Finally, three panels summarize the general fire defense problem. There is a list of suggested additional reading for those who are interested in further information on the general subject.

CONTENTS OF CHAPTER 3

"WHAT THE PLANNER NEEDS TO KNOW ABOUT FIRE IGNITION AND SPREAD"

THE THERMAL PULSE

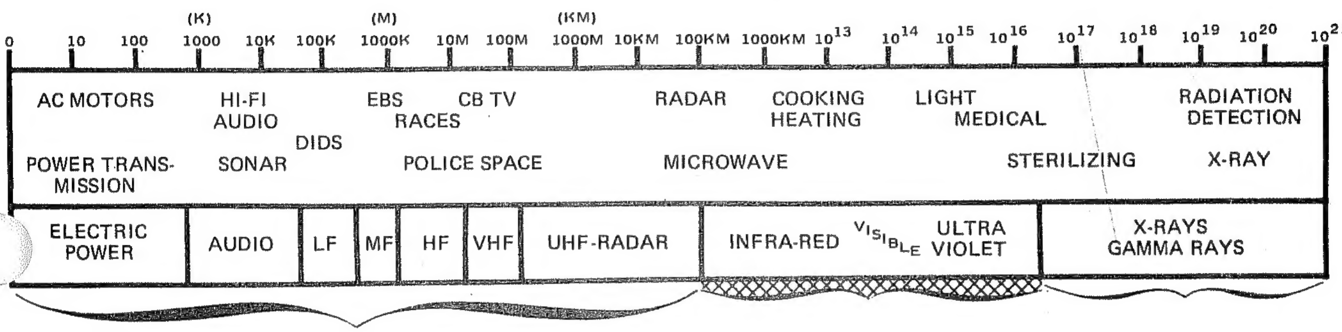
The blast wave discussed in Chapter 2 can cause fires by damaging electrical and gas lines in or near buildings. Another important cause of fires in nuclear attack is the "thermal pulse" or "heat flash" emanating from the fireball formed by an exploding weapon. An enormous amount of energy is very suddenly released in a rather small mass and volume, creating extremely high temperatures. Every hot body radiates energy. The character or "frequency" of this radiation depends on the temperature of the radiating source. At the temperature of ordinary flames, the radiation is in the infra-red, visible light, and ultraviolet region of the electromagnetic radiation spectrum shown here. But the exploding nuclear weapon is so much hotter that 80 percent of the energy is initially radiated as invisible X-rays, shown at the extreme right of the spectrum. These X-rays are very quickly absorbed in the surrounding air, heating it to form the nuclear fireball. The fireball in turn reradiates about one-third of its energy as visible light and infra-red "heat" radiation.

At Hiroshima, 80 percent of the energy emitted had been radiated outward at the speed of light by one second after the detonation. At megaton yields, the rate of emission is much slower. For a 5-MT weapon, less than 5 percent of the heat radiation is emitted in the first second. Twenty seconds are required for more than 80 percent of the pulse to be emitted. This can hardly be called a "flash"of light. The thermal pulse is sufficiently slow that its double-peaked nature is clearly evident. There is a brief flash of perhaps a tenth of a second, followed by a slower growth to full brilliance at about 2 seconds, after which the heat and light very gradually fade away. The reason for this behavior is the formation of the shock wave very shortly after the detonation, which is initially so dense as to block out the heat and light rays until it has expanded somewhat.

Most of the information in this chapter is for the planning of fire defense measures. But, first, we will describe the effects on people.

THE ELECTROMAGNETIC RADIATION SPECTRUM

Frequency in Hertz (cycles per second)



CHAPTER 4

"ELECTROMAGNETIC PULSE"

CHAPTER 3

"THERMAL RADIATION"

CHAPTER 5

"INITIAL NUCLEAR RADIATION"

PANEL 1

EFFECTS ON PEOPLE IN THE OPEN

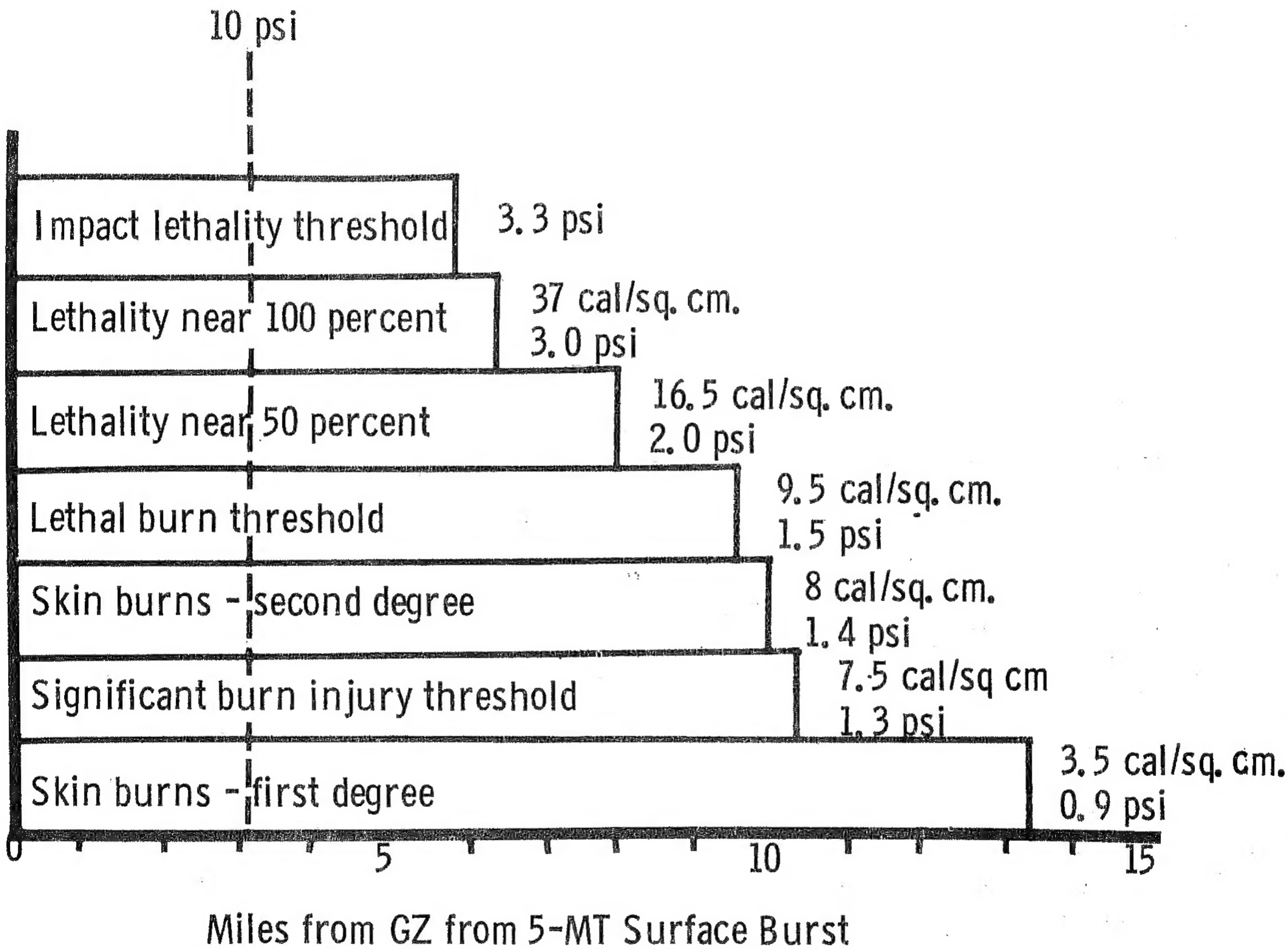
Remember the person in Chapter 2 who was standing in the open three and one-third miles from the detonation of a 5-MT ground burst? You will recall that he was engulfed in an overpressure of 10 psi about 7 seconds after the detonation and hurled by the blast wave with such violence as to cause injury and, possibly, death when he struck the ground.

Before the blast wave had reached him, he would have received lethal burns on his exposed skin and his clothing would have burst into flame. Whether the blast wind injured him critically would have been inconsequential. He could not have survived the heat from the thermal pulse.

Burns caused by heat radiation from the fireball can be the most far-ranging consequence of the immediate weapons effects. On a clear day, first degree burns can be received somewhat beyond the reach of 1 psi overpressure. A first degree burn is a burn that is painful but does not blister, like a moderate sunburn. Significant burns can be received in the area of light blast damage (1 to 2 psi). About 50 percent of those fully exposed to the fireball at 2 psi would eventually die. Death from thermal burns is almost certain at 3 psi, short of the overpressure necessary to cause impact lethality.

Notice that blast effects are expressed in English Units, such as pounds per square inch (psi). Thermal radiation effects, on the other hand, are invariably expressed in metric units, such as calories per square centimeter (cal/sq.cm.). A calorie is the amount of heat necessary to raise the temperature of a gram of water one degree centigrade, and a square centimeter is about one-sixth of a square inch.

BURN INJURIES IN OPEN
ON A CLEAR DAY



From White, C.S., **The Nature of the Problems Involved in Estimating the Immediate Casualties from Nuclear Explosions**, CEX 71.1, Lovelace Foundation, July 1971.

THERMAL SHIELDING

Of course, hardly anyone lives in an area where they would be certainly exposed to thermal radiation if a weapon should detonate while they were outside. There would be buildings, trees, hills, and other objects that might block out the radiation. Virtually any opaque material will serve to shield against the thermal pulse. And the shielding will have its main effect before the blast wave strikes.

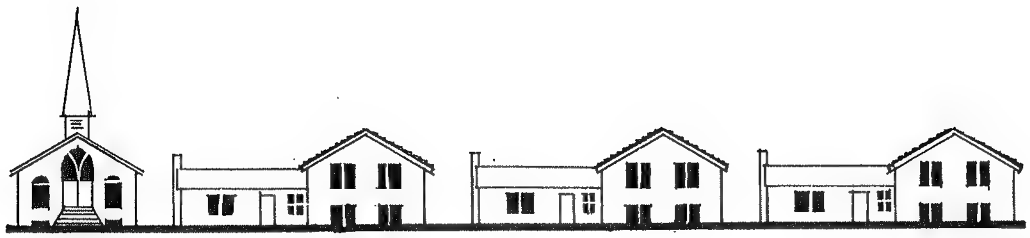
Our hypothetical person in the open at 10 psi received about 60 percent of the total thermal radiation at his location before the blast wave arrived at 7 seconds. At lower overpressures, nearly all of the radiation would be shielded out by objects before they are damaged or moved by the blast wave.

The sketch shows the current estimate of the likelihood of being shielded from thermal radiation by some structure when on the street or sidewalk. The more densely builtup the area, the more likely the shielding. These estimates are the result of thousands of observations made in typical locations in many cities. Results of these observations have also been used to estimate the likelihood that room furnishings and other fuels would be exposed to the heat radiation from the fireball.

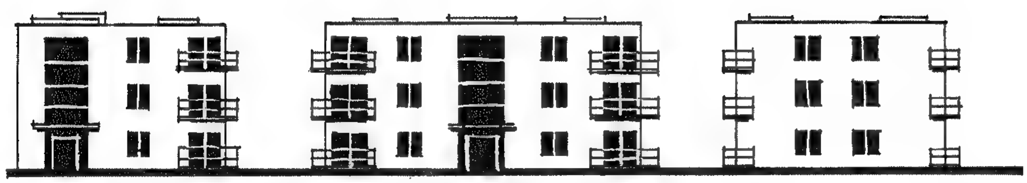
Persons caught in the open or near windows can also take advantage of the relatively slow pace of the thermal pulse from large-yield weapons. Our hypothetical person at 10 psi would have had a second or so after the initial brief flash to drop behind an embankment or into a ditch to shield himself from the main pulse. Further out, even more time would be available. In the light damage area (1 to 2 psi), evasive action within the first four seconds would avoid significant burn injury. Therefore, "duck and cover" is still good civil defense advice.

A further implication for civil defense planning is that prompt and effective warning of an impending attack will be useful in minimizing the possibility of large numbers of people in the open at the time of a nuclear detonation.

LIKELIHOOD OF THERMAL SHIELDING



ONE AND TWO FAMILY HOMES — 27-34%



THREE STORY APARTMENTS — 46-54%

TENEMENTS, COMMERCIAL, HIRISE — 88-92%

PANEL 3

VARIATIONS IN THERMAL HAZARD

Unlike the blast wave, the thermal pulse from a nuclear detonation is one of the most "fragile" weapon effects. As we have seen, almost any opaque substance shields against the heat from the thermal pulse. In addition, window glass (clean or dirty) and window screens reduce the amount of heat transmitted by 20 to 60 percent.

Natural variations in the atmosphere and weather conditions can reduce the effectiveness of the heat pulse markedly. In these days of environmental awareness, the smoggy conditions in most of our cities is well publicized. As shown here, a medium hazy day would reduce the transmitted heat to one-half that of a clear day. In other words, the range of first and second degree burn injuries would be reduced about 2 miles over those shown previously for a clear day. Significant burns to people in the open would occur only within the moderate damage region (2 to 5 psi).

In the table, we have equated thin fog to light clouds to illustrate that if a nuclear weapon were detonated as an air burst rather than on the surface, cloud cover between the burst and the ground would have a significant effect in reducing the amount of heat transmitted. Heavy clouds would shield like heavy fog. Heavy clouds above a surface burst, however, would reflect some of the heat radiation back to the ground.

In this chapter, we will use the heat effects as they would be transmitted on a clear day (or night), since this represents the most severe case to be planned for. The emergency planner should be aware of this practice and remember that the hazard will often be less severe. He should familiarize himself with the weather and visibility characteristics of his locality and should plan that information on local weather be available in the EOC for operational use in time of emergency.

EFFECT OF VISIBILITY
ON TRANSMISSION OF THERMAL PULSE

Weather	Transmitted Energy
CLEAR DAY (visibility = 12 miles)	100%
LIGHT HAZE (visibility = 6 miles)	70%
MEDIUM HAZE (visibility = 3 miles)	50%
THIN FOG or LIGHT CLOUDS (visibility = 1.2 miles)	30%
HEAVY FOG (visibility less than 1/2 mile)	10%

From Gibbons, M., **Transmissivity of the Atmosphere for Thermal Radiation from Nuclear Weapons,** USNRDL, August 1966, AD 641 481.

IGNITABLES

In general, anything that can be set afire by the application of a single match is potentially ignitable by the thermal pulse of a nuclear weapon. This means that thin fuels, such as newspapers and curtains, are necessary as tinder for igniting other combustible materials. On the other hand, these tinder fuels do not usually contain sufficient energy by themselves to cause a sustained fire. What is needed is a "fuel array" containing both tinder and other burnables.

In this chart, we show three basic groups of ignitables and their relative sensitivity to ignition by the thermal pulse. The numbers shown are the critical ignition energies, in calories per square centimeter, that are required to cause ignition of the material. Note that the energy required for ignition increases with the weapon yield, due to the increasing length of the thermal pulse. Whether a fuel will ignite and burn depends on the **rate** of energy supplied to it. After all, the sun delivers about 700 calories per square centimeter on a hot day, but much too slowly to cause things to burst into flame. If the daily energy of the sun were delivered in about 25 minutes, then there would be ignitions.

The Group I items shown are among the most sensitive kindling fuels. And yet, these ignitables are of little concern. Hardly anyone puts black curtains at their windows. In the thousands of sites that have been surveyed, none have been found. Crumpled newspaper and dry leaves are found in urban areas but, like people in the streets, they are very often not in a position to "see" the fireball and rarely are they located with other burnables to form a sufficient fuel array to cause a building fire.

Detailed surveys of urban areas have shown that essentially all fuel arrays that could produce a sustained fire are in rooms within buildings. The materials shown in Group II are typical of materials found in commercial, industrial, and residential occupancies that are reasonably susceptible to thermal ignition and that could occasionally cause a sustained fire.

The Group III ignitables are those that by themselves have a high probability of causing a sustained fire, if ignited. That is, they contain both tinder and sufficient burnables to form a fuel array. Some fire analysts consider only upholstered furniture and beds as the fuel arrays of significance. About 35 to 40 calories per square centimeter are required for ignition by a 5-MT weapon.

COMMON KINDLING FUELS

	WEAPON YIELD (MT)		
	1	5	25
	(calories per square centimeter)		
GROUP I			
Crumpled newspaper, dark picture area	7	9	15
Black lightweight cotton curtains	6	8	11
Dry rotted wood and dry leaves	6	7	10
GROUP II			
Beige lightweight cotton curtains	32	42	55
Kraft corrugated paper carton	19	22	32
White typing paper	30	42	60
Heavy dark cotton drapes	22	27	50
GROUP III			
Upholstered Furniture	28	40	56
Beds	22	34	52

INTENSITY OF THERMAL PULSE

Since we have gained an appreciation of the range of damage from blast in Chapter 2, it will be useful to relate the ignition capabilities of the thermal pulse to the key overpressures for light, moderate, and severe blast damage. As can be seen from the table, there may be occasional fires caused by Group I kindling fuels in the light damage area. Most significant fires, however, will be confined to within the 2-psi blast region. In the simplified charts of the direct effects included in Chapters 1 and 2, the 2-psi level was used as the practical limit of fire ignition.

Note that, as weapon yield increases, the thermal radiation is less in the region of low overpressure and higher in the close-in area. Megaton-yield weapons deliver about 100 calories per square centimeter at the 5-psi overpressure level almost independent of the precise weapon yield.

Recall also that on a medium hazy day, these values would be reduced to about one-half those shown.

RELATIONSHIP OF BLAST AND HEAT
(Surface Burst on a Clear Day)

BLAST OVERPRESSURE (psi)	HEAT RADIATION (cal. /sq. cm.) 1 MT	5 MT	25 MT
1	6	4	2.5
2	21	18	14
5	100	100	105
12	350	440	620
20	560	900	1500

EFFECT OF BLAST WAVE ON IGNITIONS

At Hiroshima, there was some evidence that the blast wave that followed the thermal pulse may have extinguished many ignitions. Most fires were traced to overturned charcoal braziers in residences. The 1950 **Effects of Atomic Weapons** cited the evidence for the blast wind suppression of ignitions and concluded that few of the numerous fires were due directly to thermal radiation. But, by the 1957 edition, called **The Effects of Nuclear Weapons**, this position had been so altered by scientific debate that it was generally concluded that the blast wind had no significant effect in extinguishing ignitions.

By 1970, DCPA had developed a blast simulator in which whole rooms could be accommodated. Living rooms, bedrooms, and offices were tested to see if the blast wave could blow out the fires. The upper photograph shows an office, with curtains and papers ablaze. Then, in the middle picture, the blast wave hits. And the flames are extinguished.

Overpressures of 1 psi failed to extinguish ignitions in upholstered furniture and beds and only half of the ignitions of curtains, one example being that shown here. Tests have been run at 2.5, 5, and 9 psi as well and the flames have been extinguished in all instances. However, mattresses and furniture cushions with cotton padding continued to smoulder, rekindling at times ranging from 15 minutes to several hours.

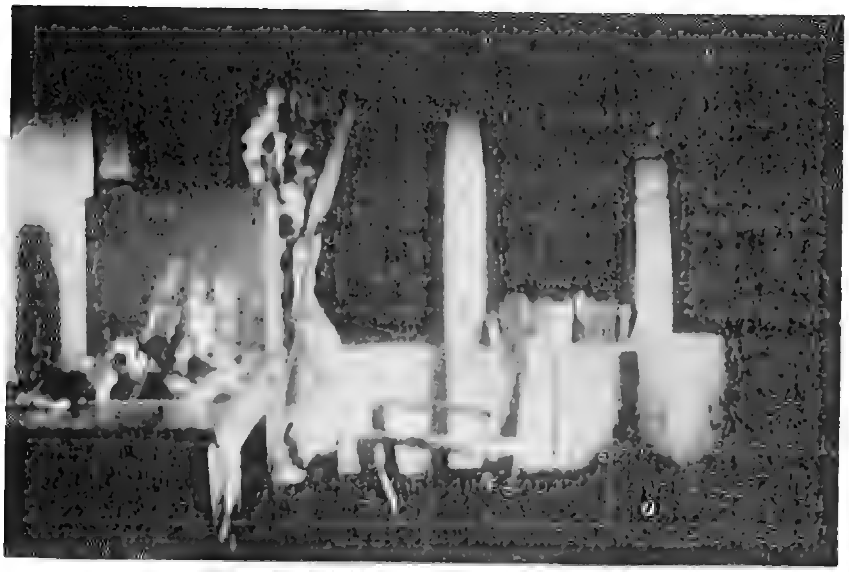
High-speed motion pictures suggest that the flames and hot gases above the burning surface are abruptly translated by the blast wind. The burning surface is thus deprived of heat from the flame and, at the same time, is brought in contact with the cooler air following the shock front, which brings the surface below the temperature required to sustain ignition. Smouldering combustion is characteristic of porous or fibrous materials in which slow combustion can persist beneath the surface after the extinguishment of flame. Since the blast wind used in the experiments to date does not persist as long as the "real" blast wind, new experiments are being designed to investigate further the problem of smouldering materials.

On the basis of these recent results, we conclude that many ignitions by the thermal pulse will be extinguished by the blast wind, greatly reducing the threat of fires. In addition, the progress of fire growth will be slowed, while those that remain continue to smoulder. In the absence of effective emergency action to suppress the smouldering fires, ultimate burn-out could occur upon rekindling of the smouldering debris.

These results also suggest that, prior to attack, curtains and drapes should be closed rather than removed, as they do not represent a significant hazard and would shield upholstered furniture and beds from the thermal pulse.

EFFECTS OF 1PSI OVERPRESSURE ON IGNITIONS

From: Goodale, Effects of Air Blast on Urban Fires URS 7009–14 Dec. 1970



PANEL 7

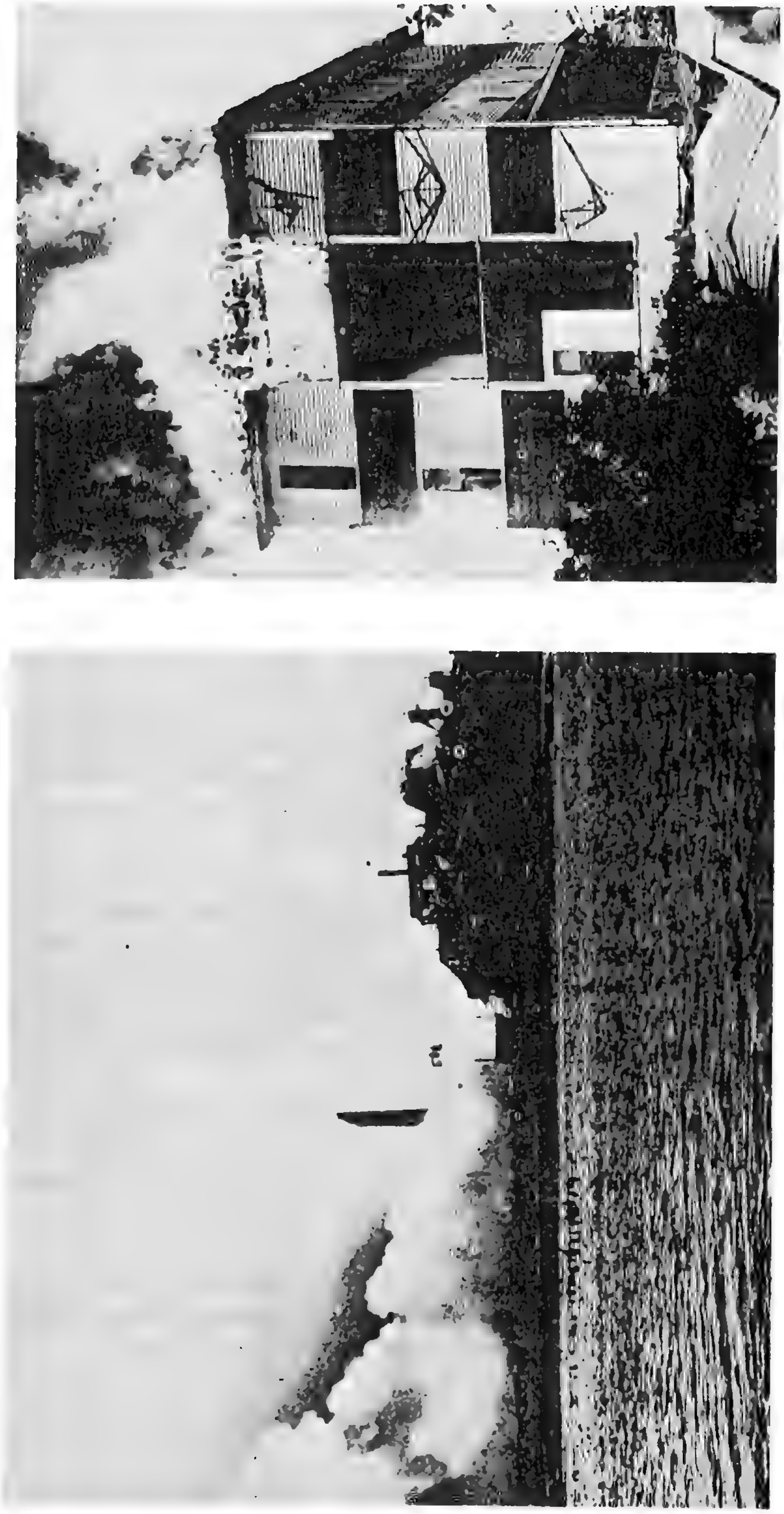
BLAST-CAUSED FIRES

As we have just seen, the arrival of the blast wave has beneficial effects in blowing out ignitions before they have had time to become firmly established, resulting at least in considerable delay in fire development and probably a large reduction in the number of sustained fires that ensue. The blast wave can also cause fires in buildings through the damage that it does.

Study has been made of the incidence and cause of "damage-caused" fires at Hiroshima, Nagasaki, peacetime explosions such as Texas City, earthquakes, tornadoes, and World War II bombings. The results indicate that flying debris and building collapse are the major causes of these "secondary" fires. Electrical wiring and equipment and gas piping and equipment are about equally vulnerable. As we saw in Chapter 2, considerable debris is formed at about 2 psi or somewhat less. Wood-frame and brick load-bearing walled buildings are weakest but industrial and special storage facilities for hazardous materials are the most vulnerable occupancies.

The upper photograph shows a major industrial fire caused by damage to phosphorus containers in the South Amboy explosion of 1950. The lower picture shows a building fire caused by tornado damage in Worcester, Massachusetts in 1953.

Overall, a review of past experience suggests that about six significant "secondary" fires can be expected in each million square feet of building floor area in the damaged area. Thus, in an area 25 percent builtup with 2-story buildings, one might find about 80 building fires per square mile from this cause. Although the basis for this estimate is less than adequate, blast-caused fires could be an important factor in the moderate damage area. If the evidence on blast-extinguishment of thermal ignitions is correct, or if poor visibility inhibits the delivery of thermal radiation, defense against blast-caused fires may be the main problem in the moderate damage region.



1950 SOUTH AMBOY EXPLOSION

From McAuliffe and Moll, **Secondary Ignitions in Nuclear Attack**, Stanford Research Institute, July 1965, AD 625 173.

PANEL 8

HOW MANY FIRES?

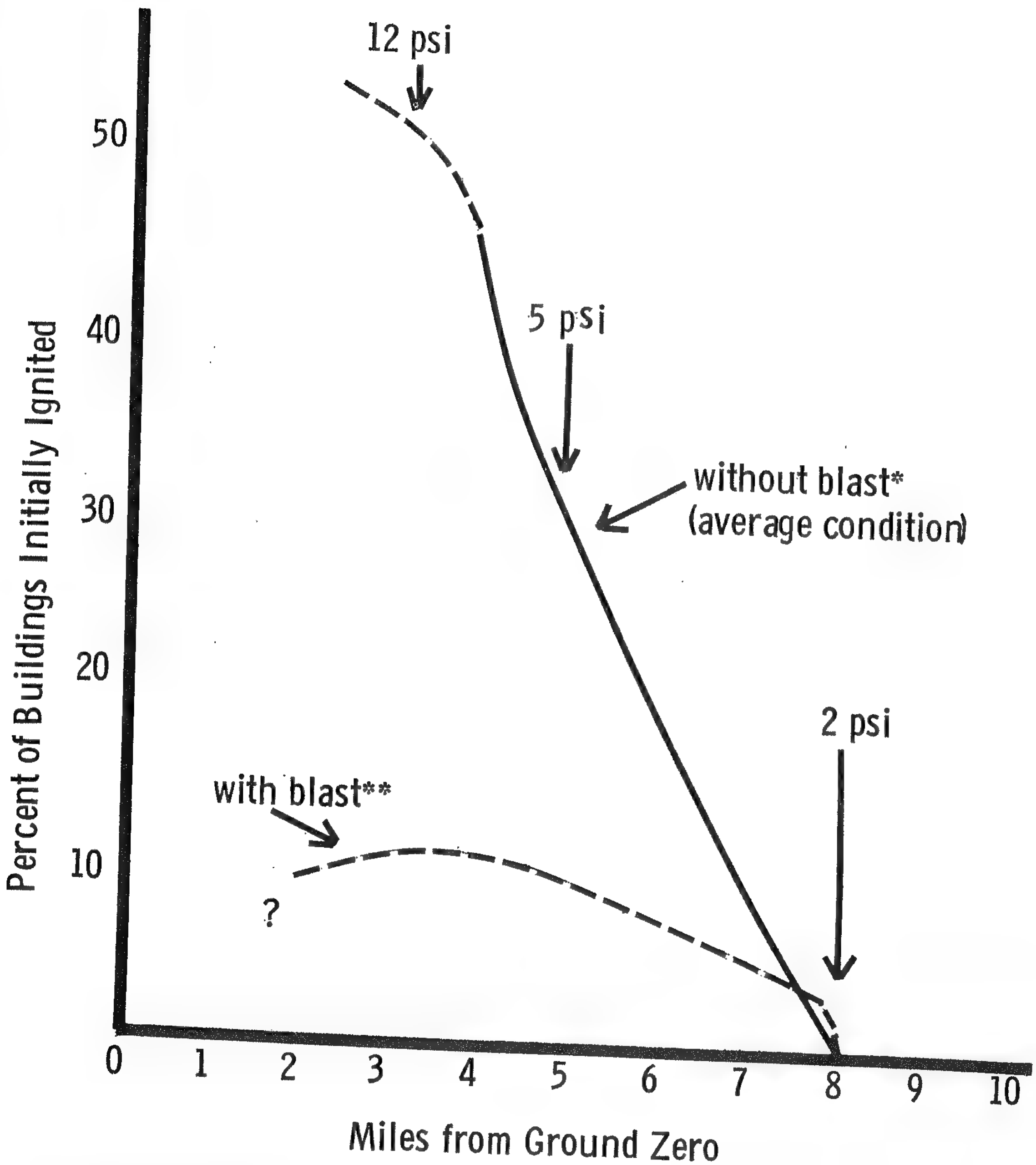
Obviously, it is important for operational planning to have a good estimate of the number of fires one can expect to be initiated by a nuclear weapon detonation. The recent evidence on the blast-wave suppression of thermal ignitions, incomplete though it is, suggests a radically different fire problem than was visualized only a few years ago. The chart shows estimates of the average percentage of buildings initially ignited with and without blast effects for the same 5-MT surface burst in Detroit for which we showed a debris map in Panel 27 of Chapter 2. These results were produced by a computerized fire model developed for DCPA by the IIT Research Institute. All of the available information on ignition of materials, their chances of being exposed to the thermal pulse, and the conditions for a sustained building fire have been incorporated into this model.

Note that building fires become negligible at the distance where 2-psi overpressure is experienced, the exact value ranging from zero to about one-tenth of one percent, depending on the type of buildings and their closeness of construction. At 5 psi, about one-third of the buildings might be ignited, if suppression by the blast wave is ignored. Inside the 5-psi region, ignition of about half the buildings would be predicted.

The lower dashed curve on the chart suggests that, if the effects of the blast wave are considered, only about 10 percent of buildings might sustain a serious fire. The steep rise at about 2 psi results from the consideration that perhaps 2 percent of all buildings would sustain "secondary" fires from blast damage to utilities and hazardous materials.

An important implication of the current state of knowledge is that the devastating "fire storm" situations that occasionally occurred in World War II are **not** in prospect in event of nuclear attack. The next few panels will explain why this is the case.

INITIAL FIRES FROM A 5-MT SURFACE BURST IN DETROIT



*From Takata and Salzberg, **Development and Application of a Complete Fire Spread Model**, IITRI, June 1963, AD 684 874.

Based on Miller, R.K., et al., **Analysis of Four Models of the Nuclear-Caused Ignitions and Early Fires in Urban Areas, The Dikewood Corporation, August 1970, AD 716 807.

PANEL 9

CASUALTIES IN LARGE FIRES

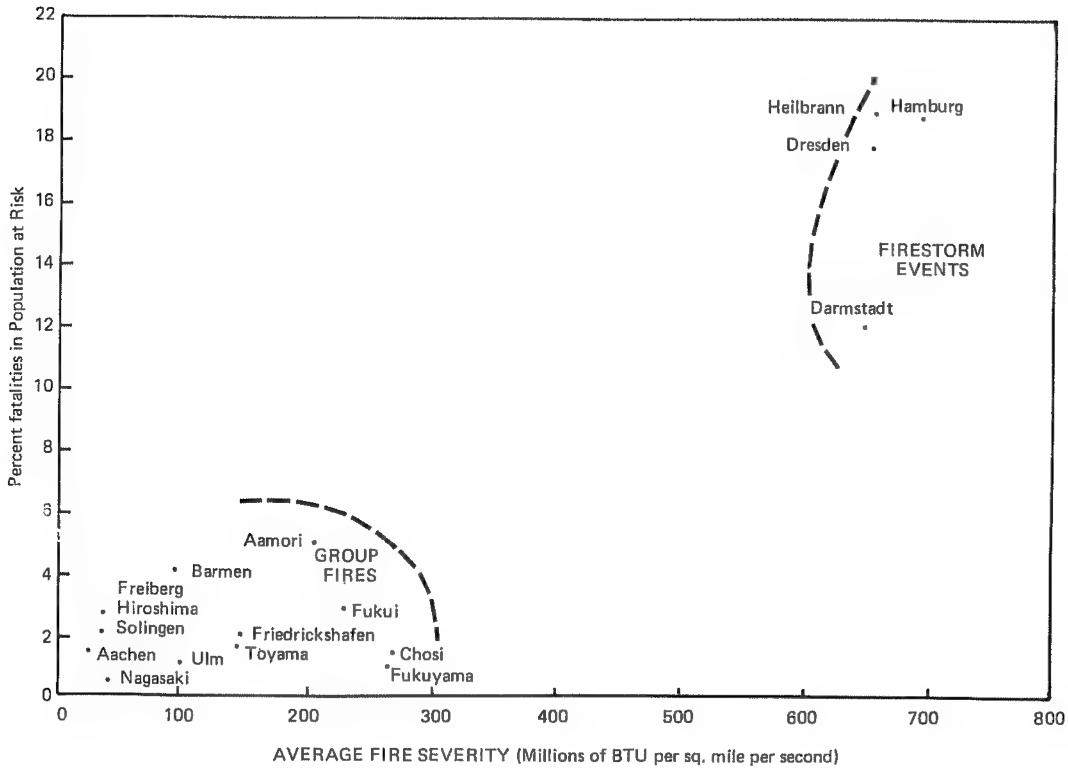
Loss of life in the large fires of World War II was considerable. The term "firestorm," coined by a German journalist, dramatically expressed the awesome nature of some of these mass fires. It took little imagination to transfer the worst of these occurrences to the event of nuclear attack. Numerous writers were led to postulate great areas of fire in which survival was unthinkable.

To gain a more objective understanding of the fire threat, DCPA has sponsored a number of studies of World War II fire experience in considerable detail. One of the results of this analysis is shown here. The loss of life among the population at risk for a large number of war fires was found to be related to the fire severity. The severity of a large fire was expressed in terms of the average heat output as measured in millions of BTU per square mile of fire area per second. [A BTU (British Thermal Unit) is similar to a calorie, being the amount of heat necessary to raise the temperature of a pound of water 1 degree Fahrenheit. A BTU is equal to 252 calories.]

Note that a large number of wartime fires are classed as "group fires." The fire severity ranged up to about 300 million BTU per square mile per second and the loss of life ranged up to 5 percent of the population at risk. Note also that the fires caused by the nuclear detonations at Hiroshima and Nagasaki are among the least severe.

At the other end of the chart are a relatively few war fires labeled "firestorm events." These cases generated a fire severity between 600 and 700 million BTU per square mile per second. The corresponding loss of life ranged between 12 and 20 percent of the population at risk. All of these "firestorms" occurred in German cities.

FATALITIES IN WORLD WAR II FIRES*



*Lommasson and Keller, **A Macroscopic View of Fire Phenomenology and Mortality Predictions,** Dikewood Corporation, DC-TN-1058-1, December 1966.

PANEL 10

FIRESTORM POSSIBILITIES

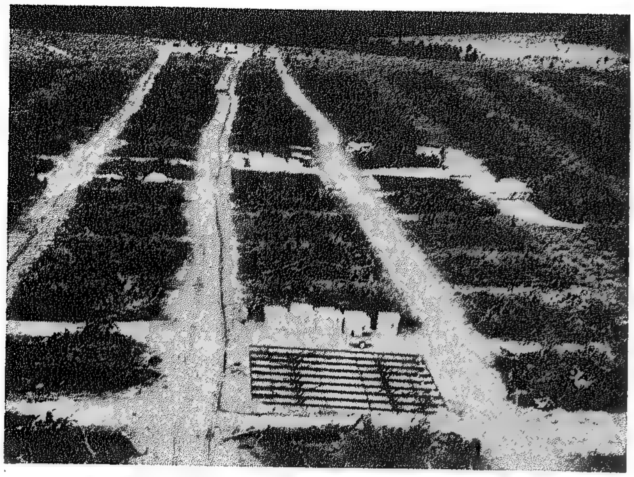
The marked increase in loss of life found in "firestorm events" focused early attention on the nature of these fires and the necessary conditions for their occurrence. The fire research community is not entirely agreed on what constitutes a firestorm, except in broad qualitative terms. What is generally meant is a mass fire characterized by high-velocity inrushing winds, a well-developed convection or smoke column reaching high into the atmosphere, and little spread beyond the area that contained the initial fires. It has been considered significant that the only clear-cut firestorm events in World War II occurred in German cities, of which the Hamburg fire was the most extreme and the most studied.

Research has been done relating fire-induced inrush wind velocities to the energy release rate of these large fires. In Germany, velocities of 50 miles per hour or greater were associated with firestorms. Winds of 40 mph or less were associated with group fires. Peak fire-induced winds at Hiroshima were estimated to reach 35 mph, which places it well down in the group fire category.

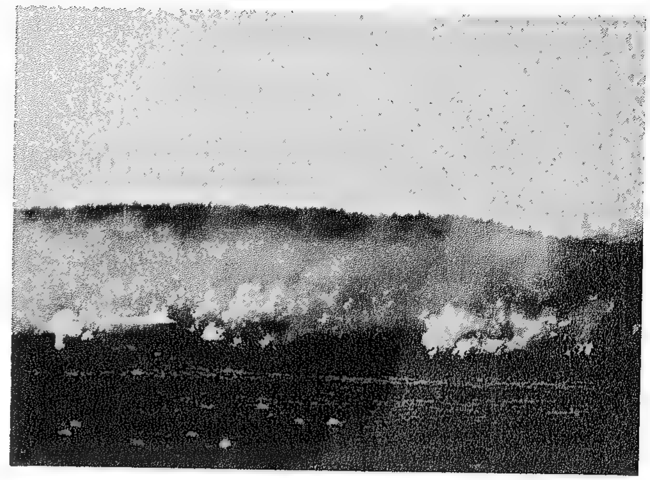
Group fires burn outward with spread from the initial fires determined by the closeness of buildings and the wind conditions prevailing at the time. Firestorms apparently involve rapid spread within the firestorm area to initially unignited structures, aided most probably by the high inrush winds. This one hundred percent involvement in firestorms is confirmed by observer reports.

From 1963 to 1967, OCD participated jointly with the U.S. Forest Service and the Defense Nuclear Agency in a series of mass fire experiments called Operation FLAMBEAU. Slash timber was piled in large arrays representing houses and burned to measure the resulting fire environment. The left-hand picture shows the largest array, occupying 40 acres, before the burn. The right-hand picture shows the array at the height of the burn. Through these tests and other work, it was confirmed that the energy release from a large fire depended on the amount of fuel available, the burning rate of the individual buildings, and the weather conditions at the time of the fire. The table indicates the conditions thought necessary for production of a firestorm.

Since we now estimate that only about 10 percent of the buildings will be ignited by a nuclear detonation, one of the criteria for firestorm conditions, that at least 50 percent be on fire initially, is not met. In other words, present evidence suggests that the most severe nuclear fire situation will be similar to that which occurred in Hiroshima. The information in the next few panels confirms this view.



Flambeau plot before burning



Flambeau plot during burning

CRITERIA FOR PREDICTING FIRESTORMS*

- Greater than 8 pounds of fuel per square foot of fire area.
- Greater than 50 percent of structures on fire initially.
- Surface wind less than 8 miles per hour initially.
- Fire area greater than 0.5 square mile.

*Rodden, R.M., et al, **Exploratory Analysis of Fire Storms**, Stanford Research Institute, 1965, AD 616 638.

FUEL LOADING AND BUILTUPNESS

The total amount of combustibles in a building, including both structure and contents, has an important bearing on the potential severity of fires. Each pound of combustibles typically generates about 8000 BTU upon burning.

An estimated range of fuel loadings in typical building uses or "occupancies" is shown here. Whether a particular structure would have a fuel loading near the high or low end of the range shown depends mainly on the type of construction of the building. For example, the typical combustible contents of residences averages about 3.5 pounds per square foot of floor area, so a total fuel loading near 20 would indicate a home constructed largely of wood whereas a fuel loading of 10 pounds per square foot would be appropriate to brick or other masonry construction.

Similarly, the combustible contents of office and commercial space ranges from 7 to 10 pounds per square foot of floor area. Combustible contents of industrial and storage buildings vary quite widely depending on the nature of the operations involved.

Another important factor in fire growth and spread is the density of construction. This factor is called "building density" or "builtupness" and is expressed usually as the fraction of the total area, including streets, parks, and the like, that is under roof. Typically, the building density in residential tracts ranges from about 10 to 25 percent; that in commercial and downtown areas up to 40 percent. Industrial and storage areas can vary widely in building density. Those with very high density are often referred to as "massive industrial" areas.

The combination of builtupness and fuel loading per square foot of building gives the fuel loading per square foot of fire area. The firestorm area at Hamburg was about 45 percent builtup with buildings having a fuel loading of about 70 pounds per square foot. This would mean about 32 pounds of fuel per square foot of fire area, four times the 8 pounds per square foot estimated as the minimum necessary for firestorm conditions.

In contrast, a residential area 10 percent builtup with single-story wood-frame detached homes would have a fuel loading of only 2 pounds per square foot, well below the criterion.

ESTIMATED RANGE OF FUEL LOADINGS

OCCUPANCY	FUEL LOAD PER STORY* (pounds per square foot)
Hi-Rise Residential (Fire Resistive)	3 - 5
Brick or Frame Residential	10 - 20
Office and Commercial	10 - 40
Industrial	0 - 30
Storage	20 - 80

*Includes building structure and contents.

BURNING TIMES

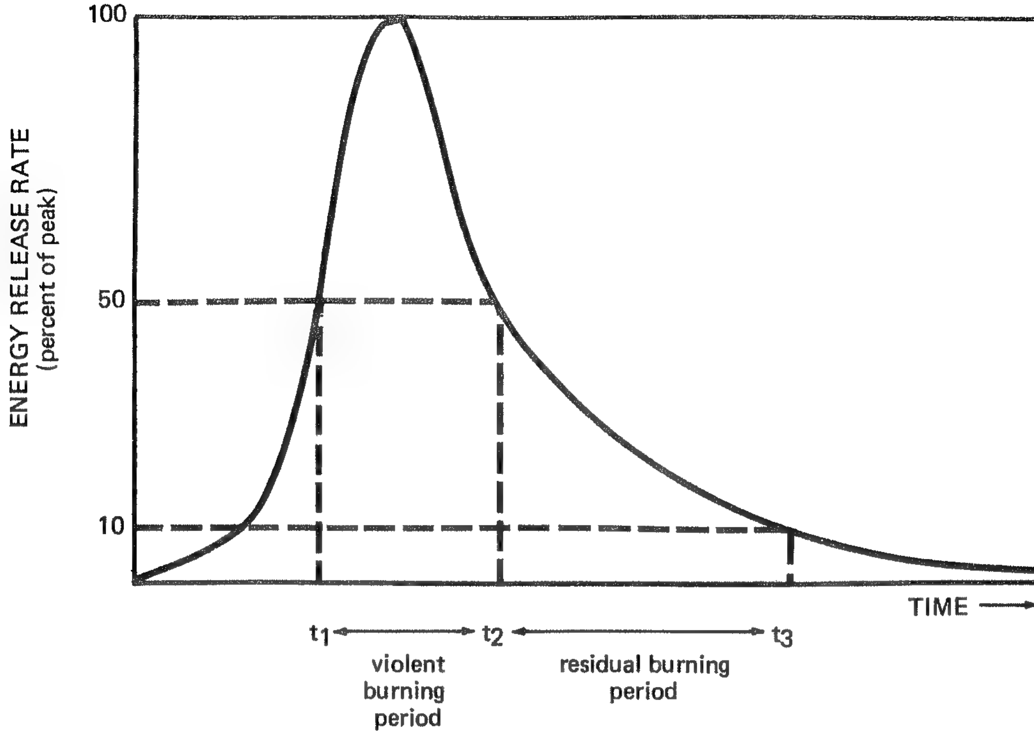
Perhaps the most important factor in fire severity is the rate at which buildings burn. either singly or in combination. This factor is also the most difficult to estimate because good measurements are rarely made in peacetime fire incidents. A study of the available information was made in the early 1960s, the results of which are shown here.

The burning time of a building is generally divided into two periods: (1) the violent burning period, and (2) the residual burning period. The violent burning period is defined as the period of time between the instant when the rate of energy release reaches 50 percent of the eventual peak release rate and the instant when the rate drops once more to 50 percent of the peak level, as shown in the diagram. The heat output during the time period prior to the 50 percent level is ignored. Although the heat output outside the buiding is small during this initial stage, the period of time can be long. Since this period is where fire defense can be most effective, we will give it considerable attention beginning with Panel 15, though it is ignored here.

The residual burning period is taken to be the period of time between the instant when the rate of energy release, having peaked, reaches 50 percent of the peak value and the instant when the rate reaches 10 percent of the peak level. This is the period between time, t_2, and time, t_3, in the diagram. Note in the table that the residual burning period contributes little to the total energy release when lightly constructed houses burn but is a major source of heat output in the heaviest types of construction. Moreover, the total burning time is very much longer for heavy construction than it is for light construction, being about 3 hours for "downtown" massive construction.

Regrettably, our knowledge of burning times is deficient. Most of the good data are for the controlled burning of undamaged, individual buildings. As we have seen in Chapter 2 blast damage can alter radically the structures that could later burn. We are just beginning to gain an understanding of the effects of blast damage on the subsequent fire threat. Some results are given in later panels. The available information suggests that the burning times shown here are appropriate for blast-damaged buildings.

ESTIMATES OF BURNING TIMES



BURNING TIMES FOR URBAN STRUCTURES*

CONSTRUCTION TYPE	VIOLENT BURNING TIME (min.)	VIOLENT BURNING ENERGY RELEASE (percent)	RESIDUAL BURNING TIME (min.)	RESIDUAL BURNING ENERGY RELEASE (percent)
Light Residential	10	80	12	20
Heavy Residential	13	70	20	30
Commercial	25	60	60	40
City Center and Massive Manufacturing	55	30	120	70

*From Chandler, et al., **Prediction of Fire Spread Following Nuclear Explosions,** Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, 1963.

FIRE SEVERITY

We have now covered the chief factors involved in estimates of fire severity in nuclear attack. These are: (1) the fuel loading in individual buildings, (2) the builtupness or building density of the area, (3) the burning rate of buildings, and (4) the proportion of buildings burning at the same time. It will be useful to summarize what this information means.

We have already mentioned that, in the Hamburg "firestorm" area, there was a fuel loading of about 32 pounds of fuel per square foot of fire area. Using the heat value of combustibles as about 8000 BTU per pound, and a burning time of 2 hours and 55 minutes for buildings in city centers, we can calculate an average energy release rate, or "power density" as the fire research community prefers to call it, of about 685 million BTU per square mile per second—which is not far from the estimate in the World War II fire casualty chart shown in Panel 10.

At Hamburg, at least 50 percent of the structures were initially set on fire and the burning period was so long that the others also were burning at the same time as those initially on fire. The upper calculation shown here assumes this.

Now, take another example—2-story brick residences, perhaps many row houses, so that the area is 25 percent built-up. As we have seen, such houses might have about 10 pounds of fuel per square foot per story or 20 pounds per square foot for 2-story buildings. At 25 percent builtupness, this would be 5 pounds of fuel per square foot of fire area, less than the "magic number" of 8 pounds previously given as the threshold for possible firestorm events. Using a burning period of 33 minutes (1980 seconds) for "heavy residential" construction and 10 percent of the buildings burning simultaneously, we obtain a fire severity of about 56 million BTU per square mile per second, somewhat higher than that estimated for Hiroshima. In Japan, the burning time of most buildings was short, since there was a great deal of light construction. Only a portion of buildings were burning at the same time, and hence, firestorms did not result. This appears to be the situation in American cities as well and perhaps is the case for all nuclear detonations.

Fire defense can be planned for the fire environment expected in nuclear attack. What measures will be effective can be determined from the details of fire growth and spread described in the next series of panels.

SOME TRIAL CALCULATIONS

<u>The Hamburg Case:</u>

Fire Severity - 8000 BTU per pound of fuel <u>times</u> 32 pounds of fuel per square foot of fire area <u>times</u> 28 million square feet per square mile <u>divided by</u> 10,500 seconds burning time for "city center and massive manufacturing" areas

<u>or</u>

Fire Severity = about 685 million BTU per square mile per second <u>average</u> rate of energy release.

<u>Heavy Residential Case in Nuclear Attack</u>

Fire Severity - 8000 BTU per pound of fuel <u>times</u> 10 pounds of fuel per square foot per story in brick buildings <u>times</u> 2 stories average building height <u>times</u> 0.25 fraction of the area covered by buildings <u>times</u> 28 million square feet per square mile <u>divided by</u> 1980 seconds burning time in "heavy residential" construction <u>times</u> 1/10 of the buildings burning at one time,

<u>or</u>

Fire Severity = about 56 million BTU per square mile per second <u>average</u> rate of energy release.

ROOM FLASHOVER

The ignition of kindling fuels does not immediately result in a room fire. In fact, isolated small quantities of fuel, such as a curtain or drape, are very likely to be completely consumed with no further fire spread. Sometimes even major furniture items may burn without any large flame buildup. But, for the most part, ignition of major upholstered furniture or beds, either by the thermal pulse directly, or by spread from other kindling fuels, will result in room "flashover."

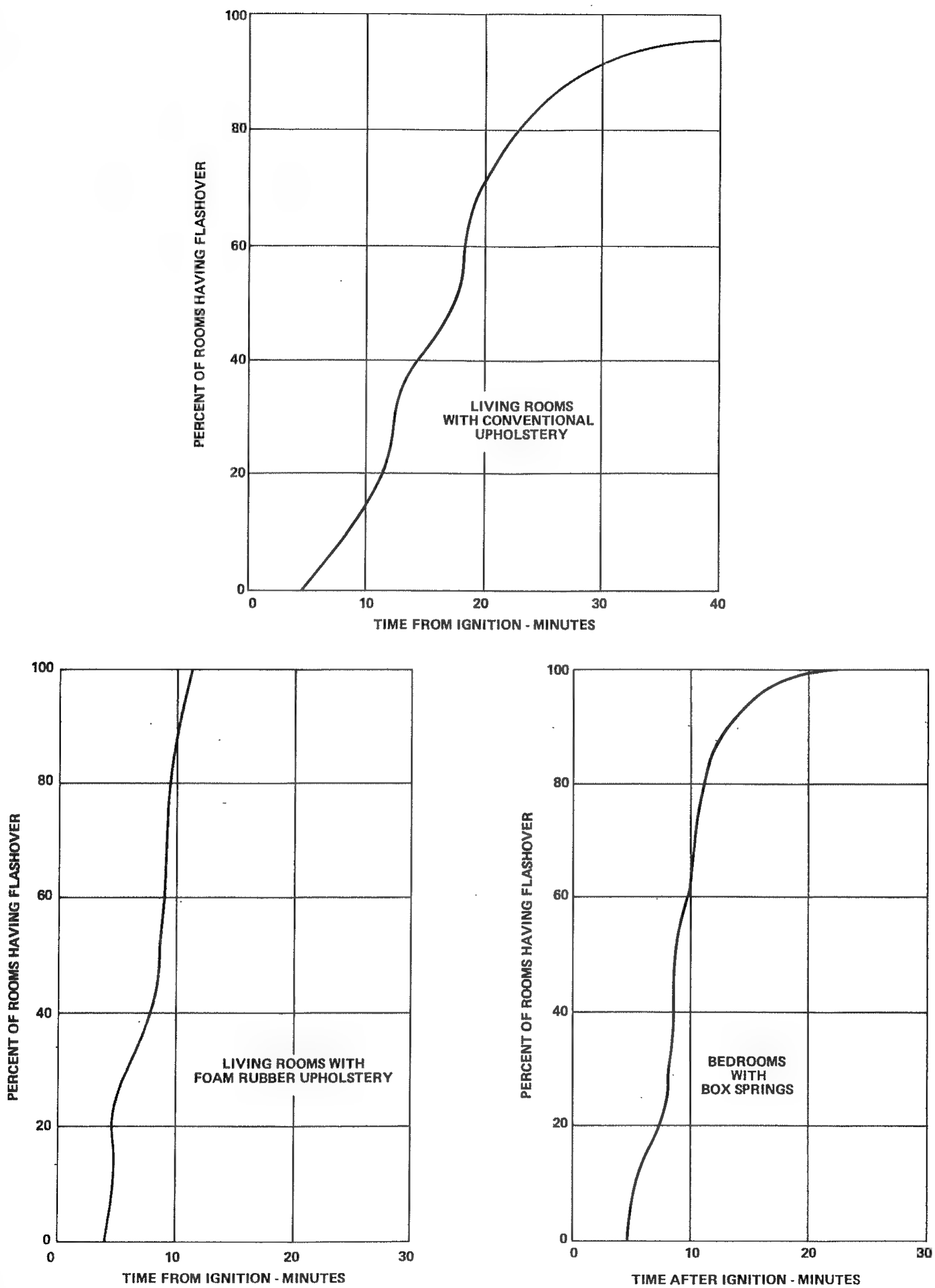
"Flashover" is a rapid stage of the growth of a room fire when the uninvolved combustibles suddenly ignite. When this occurs, as is usual in residential fires, the whole room appears to burst into flame almost explosively. Flashover does not mean that the fire has spread to adjoining rooms, but involvement of additional rooms usually takes place shortly thereafter. Flashover is significant in two ways: (1) it signals the end of the time when simple self-help measures suffice to extinguish the fire, and (2) it is about the time when the fire is evident from the street or at a distance because flames and smoke emerge from the windows.

DCPA has sponsored experiments on the time interval between ignition and subsequent flashover to aid in determining the number and training of teams required to extinguish the fires. Living room and bedroom furniture was placed in a test room. About 80 separate experiments were conducted to get the information shown here.

The upper chart shows the results for living room furniture with conventional cotton felt or fiber padding. Some rooms flash as early as 5 minutes, but only 16 percent have flashover at 10 minutes, 50 percent at 16 minutes, and some rooms never flash. In contrast the lower left chart shows that foam rubber upholstery results in rapid flashover between 5 and 12 minutes after ignition. Beds with box springs flash nearly as rapidly, as shown at lower right. Beds with open coil springs never result in room flashover.

The difference in rate of fire growth between conventional and foam rubber upholstered furniture and between mattresses on box springs and mattresses on open coil springs is marked. Your local fire service may be interested in reviewing this information as it may have application to peacetime fire defense.

TIME TO ROOM FLASHOVER*



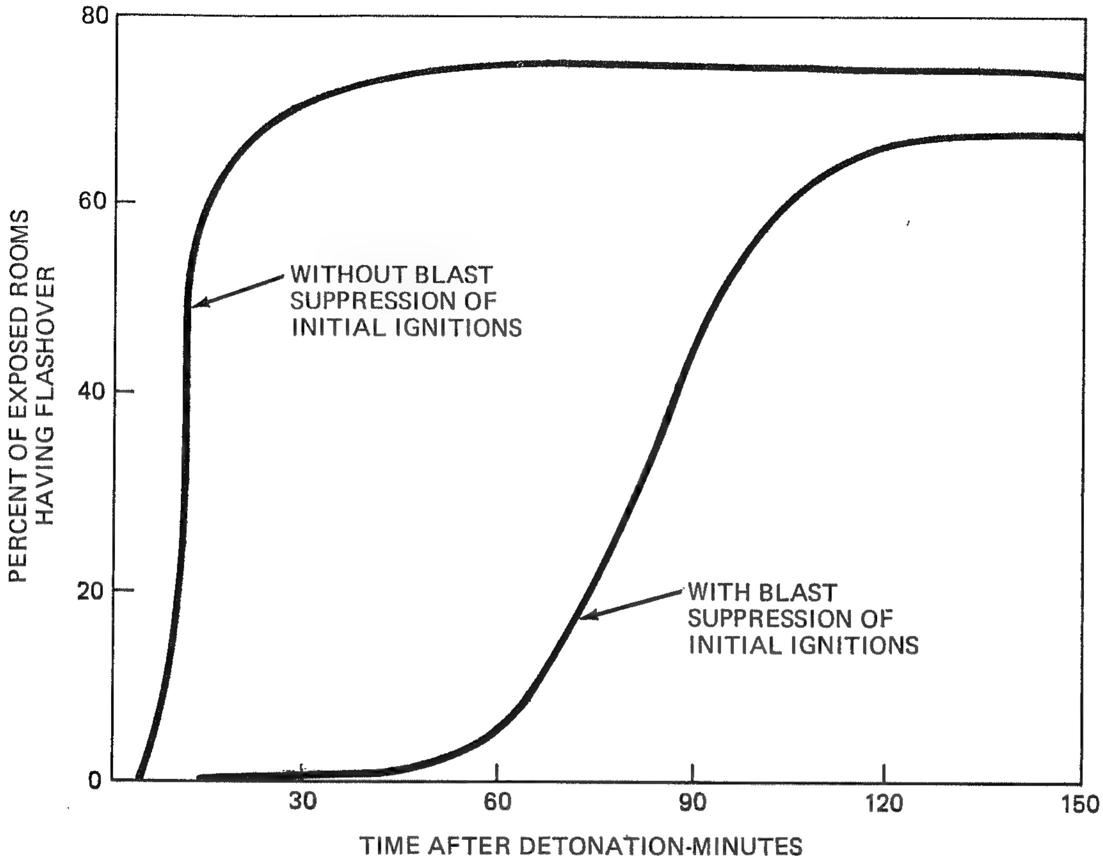
*From Vodvarka and Waterman, **Fire Behavior, Ignition to Flashover,** IITRI, 1965, AD 618 414.

FLASHOVER TIMES IN RESIDENTIAL AREAS

The typical residential area will have a mixture of upholstery types and bedspring types. Shown here is an example composite of the flashover results of Panel 15, assuming one living room for every three bedrooms. Without blast suppression of initial ignitions, nearly three-quarters of the exposed rooms would be expected to have flashover, half of these in the first 10 minutes after detonation.

With blast suppression of initial ignitions, much more time would be available to institute self-help measures to locate and remove smouldering furniture and other items. Furniture with foam rubber upholstery would not smoulder, but the remainder could rekindle. Assuming that flaming reoccurred randomly between 15 minutes and two hours after detonation, it would appear from this example that self-help firefighting organized within 30 minutes to one hour could have a major effect on the suppression of these incipient fires.

RESIDENTIAL ROOM FIRES



Composition of Rooms:

1/4 Living Rooms

2/3 Conventional Upholstery

1/3 Foam Rubber Upholstery

3/4 Bedrooms

2/3 Box Springs

1/3 Open Coil Springs

FIRE GROWTH IN RESIDENCES

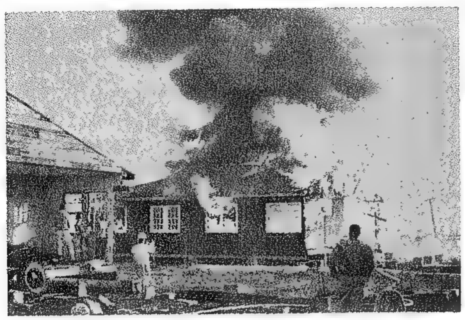
This series of photographs of the burning of a test structure representative of a wood-frame residence will illustrate the course of events following flashover of a single room. The first photograph, taken at 12 minutes after ignition, shows the situation shortly after flash-over of the ignition room. The fire has penetrated into the attic space above the room. At 20 minutes after ignition, the fire has spread rapidly throughout the attic space, part of the roof is ablaze, and rooms neighboring the ignition room have flashed over.

The third photograph shows the building totally involved at approximately the time of peak burning, as measured by the heat received by radiometers located outside the building. At this time, 27 minutes after ignition, the roof has burned through and collapsed. Roof collapse is often associated with the peak radiation from a burning structure. The final photograph, taken at 40 minutes after ignition, shows the building with essentially all the fuel above the floor level burned away.

The maximum burning rate for this test at the DCPA Research Facility, Camp Parks, California, occurred at about 26 minutes after ignition and the violent burning period was approximately 20 minutes. In addition to test burns of the type shown, the IIT Research Institute has instrumented and burned a number of two-story wood-frame residences being removed in urban renewal and highway construction programs. Violent burning periods have ranged from 19 to 28 minutes, depending on wind conditions, whether the ignition was in an upwind or downwind room and whether the ignition was on the second story or the ground floor. In general, violent burning periods in undamaged residences have averaged about twice as long as the 10 to 13 minutes we used in calculating firestorm potential.

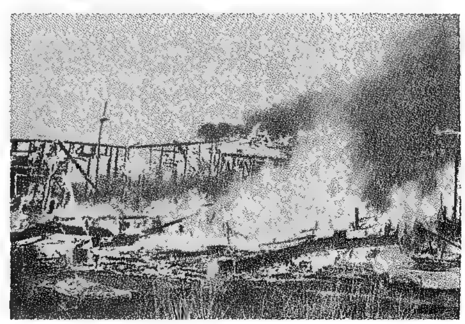
A useful generalization that comes from this experimental work is that the fire tends to double in volume every 3 to 7 minutes after the initial flashover under conditions of moderate wind or upward spread. Thus, if rooms are nearly the same size, an adjacent room will flash about 5 minutes after the first. Five minutes later, about 4 rooms would be engulfed and shortly thereafter the entire building would be involved. For very low winds or where up-ward spread cannot occur, the doubling time is longer—from 9 to 14 minutes.

12 MINUTES AFTER IGNITION



20 MINUTES AFTER IGNITION

27 MINUTES AFTER IGNITION



40 MINUTES AFTER IGNITION

From Butler, C.P., **Measurements of the Dynamics of Structural Fires,** Stanford Research Institute, August 1970, AD 716 327.

PANEL 17

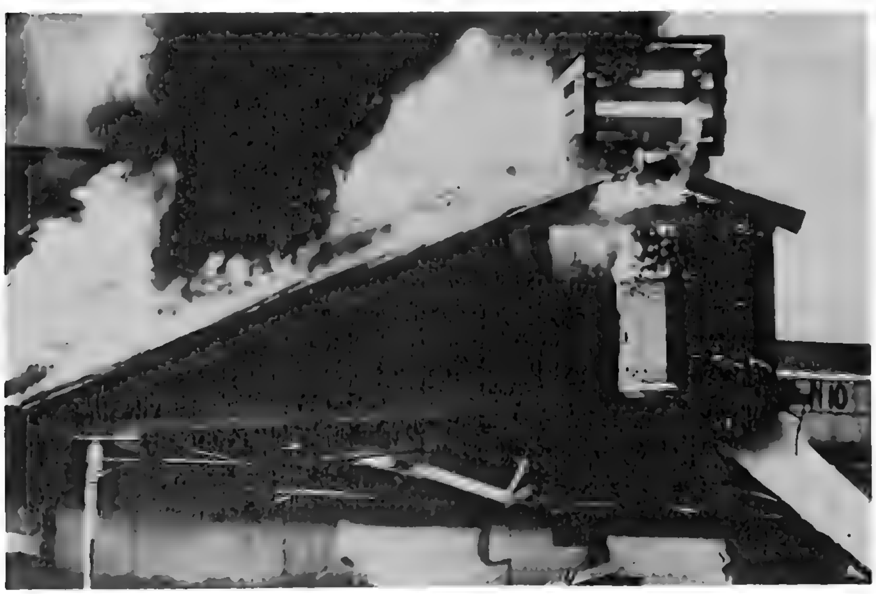
FIRE GROWTH IN DAMAGED RESIDENCES

Only a few fire experiments have been performed in which the buildings have been damaged as they would be under most nuclear attack conditions. The upper photograph shows a damaged test structure, otherwise identical to the one on the previous page. The roof has been collapsed onto the floor on one side of the building. The lower photograph shows the damaged structure totally involved in flame.

In this experiment, the time required for the flames to spread from the ignition site to the far end of the building was about the same as observed before for flame spread in the attic but, in the damaged building, the spread was rapid throughout the whole volume. As a consequence, the fire peaked very rapidly, once the building was involved. The violent burning period was only seven minutes long and the rate of fuel consumption at peak burning was about twice that of the undamaged structure.

Two other experiments, in which dynamite was used to damage wood-frame houses prior to burning, gave violent burning periods of 9 minutes and 12 minutes. On the basis of such limited evidence, it would appear that a 10-minute estimate for the violent burning period for "light-residential" buildings is a good approximation in the 2- to 3-psi region of a nuclear detonation.

DAMAGED TEST BUILDING



BURNING OF DAMAGED BUILDING

FIRE GROWTH IN LARGER BUILDINGS

Our knowledge of fire growth in larger buildings is limited to observations of peacetime fires in undamaged buildings. These observations confirm that undamaged buildings burn slowly, with the following time factors considered average:

(a) 13 minutes from compartment flashover to stair flashover.

(b) 10 minutes from stair flashover to stair flashover on all floors above.

(c) 30 minutes from stair flashover to flashover of stairwell on next lower story.

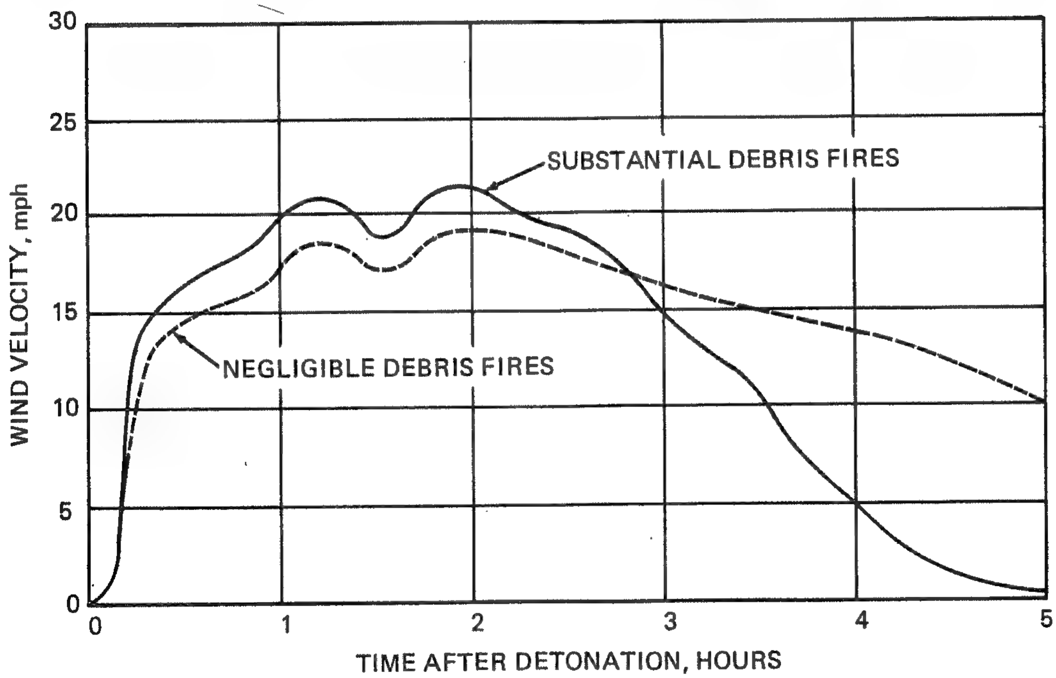
(d) 42 minutes from compartment flashover to ceiling penetration to next story.

(e) 51 minutes from top compartment flashover to roof collapse.

The upper photograph shows a view of the Loop District of Chicago. Similar concentrations of tall buildings make up the city center of most large U.S. cities. Despite the high fuel loading associated with multi-story buildings, a detailed analysis of the fire history in the Loop District following a 5-MT surface burst at a distance of 5 miles (about 5-psi blast overpressure in the Loop) did not forecast a firestorm event. The lower chart shows that the maximum inrush winds were estimated to be about 20 miles per hour, far below the wind velocities associated with the German firestorm events. The recently-developed information on the effects of the blast wave in suppressing ignitions was **not** taken into account in this analysis.

There are a number of reasons for this outcome. Modern high-rise office buildings are among the least susceptible to fire and fire spread. Because of the great amount of shielding provided by the taller buildings, ignitions are largely confined to the upper floors of most buildings. Most of the buildings are of fire-resistive construction. It is estimated that about one hour and 15 minutes would be required after flashover for fire to penetrate to the next floor below in such buildings. As a consequence, those buildings that could support a sustained fire would burn slowly from the upper floors down. However, a substantial part of the contents of the upper floors will have become debris in the streets at 5-psi blast overpressure. Smouldering items might start fires in this debris.

DOWNTOWN CHICAGO



ESTIMATED FIRE WINDS IN CHICAGO LOOP*
(from 5-MT surface burst at 5 miles)

*From Takata, A.N. **Fire Spread in High Density High-Rise Buildings**, IITRI, February 1971, AD 719 731.

FIRE SPREAD BETWEEN BUILDINGS

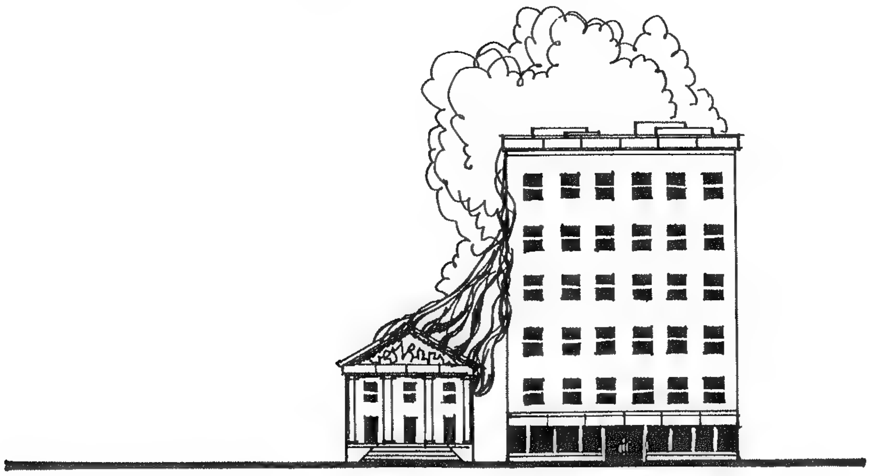
Growth of fires within buildings represents only part of the fire problem. Fire spread between buildings is a major factor in wartime fires. There are three basic ways in which fires may spread from burning buildings to buildings not yet ignited. The first, called "convection," consists of heating of nearby combustibles by direct flame contact or hot gases of an active fire until sustained ignition occurs. This is a very short-range mechanism, of interest mainly for buildings closely adjoining or with common walls. Convection is the main means of fire spread within buildings and is of concern in peacetime fires where a taller building may be at hazard from its smaller neighbor, as shown in the upper sketch. As we have seen, it is far more likely in nuclear attack that ignitions will be confined to the upper floors of the taller building.

The second means of fire spread is radiation. The flaming mass of a burning building radiates heat, which, in sufficient quantity, can raise the temperature of exposed elements of nearby buildings to the kindling point. Through this mechanism, though on a much smaller scale, the flaming building causes ignitions much like the nuclear fireball does and our previous discussion of ignitables and their behavior is pertinent. In particular, it is **rate** of heat input, usually measured in calories per square centimeter **per second**, that determines whether ignition will occur.

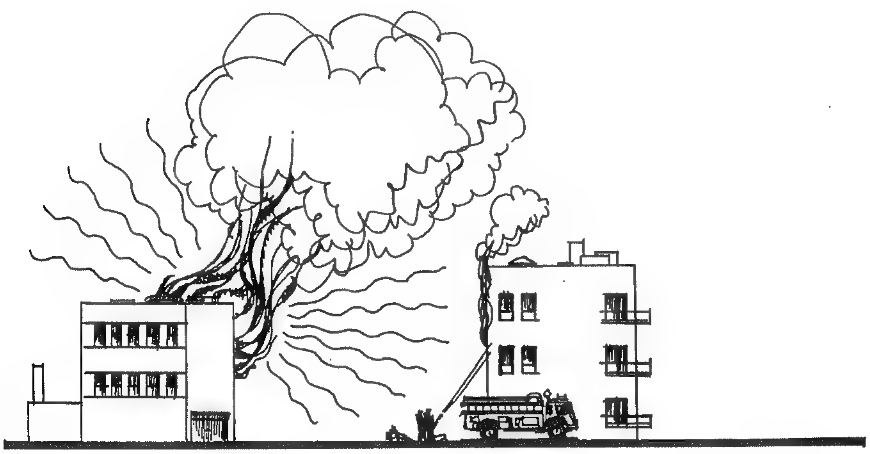
The threat of fire spread through radiation is common in peacetime fires. "Control of exposure" is a major firefighting measure, which means to play a hose on the exposed surfaces of nearby structures to cool them below the kindling temperature. This activity is shown in the middle sketch.

The final means of fire spread is by the transport of "firebrands" by the wind. This can be a very long-range mechanism under many circumstances. Spot fires from firebrands are common in forest fires. In the great Baltimore fire of 1904, firebrands caused new building fires over one-half mile downwind of the burning fire front.

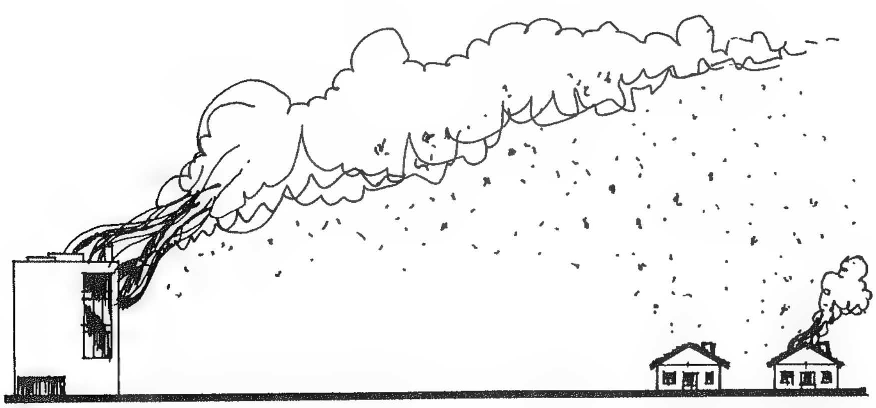
FIRE SPREAD BETWEEN BUILDINGS



FIRE SPREAD BY CONVECTION



FIRE SPREAD BY RADIATION



FIRE SPREAD BY FIREBRANDS

FIRE SPREAD BY RADIATION

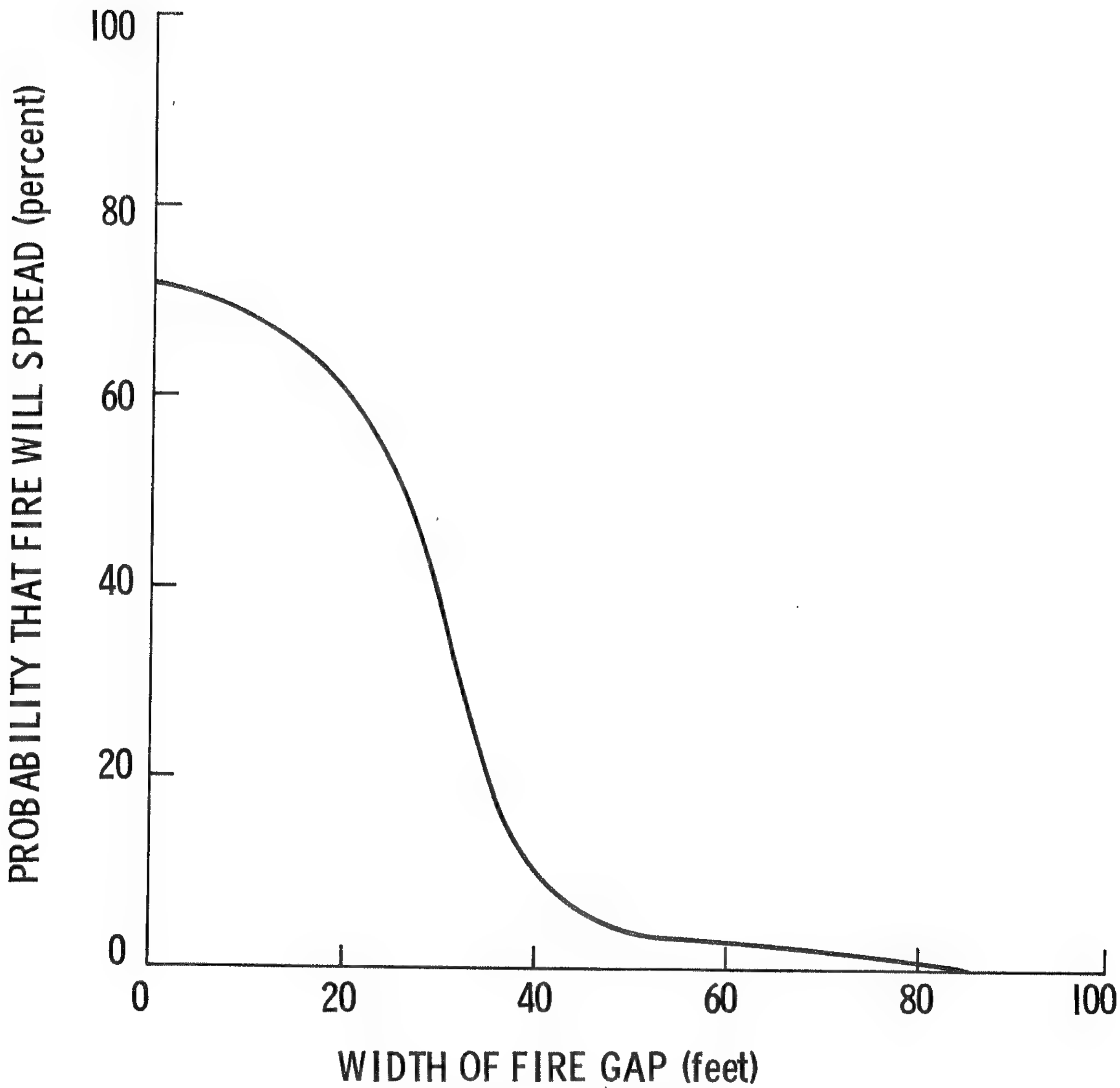
Of the three mechanisms of fire spread, spread by radiation is likely to be the most important. An understanding of this mechanism can be gained from common experience. If one stands within a few feet of a campfire or a well-laid fire in a fireplace, one may experience an unpleasant sensation or pain from the radiated heat on exposed skin. If one were observing a burning building, the same heat sensation might be felt at a distance many tens of feet from the much larger fire. More precisely, the rate of heat energy received by radiation depends entirely on the **fraction** or **proportion** of the **field-of-view** that is occupied by the flames.

The flames emit heat radiation at a rate of about 4 calories per square centimeter per second. If an object, such as a piece of wood, is placed in contact with the flames so that flames occupy the entire hemisphere that the face of the object can "see," the object receives the full 4 calories per square centimeter per second. If the object were moved away from the flames so that only half the field-of-view was occupied by flames, then only 2 calories per square centimeter per second would be received by the face of the object. It so happens that wood can be ignited by a heat input rate of about 0.4 calories per square centimeter per second, so that whenever the flame area from a neighboring fire occupies more than about 10 percent of the field of view, ignition of wood by heat radiation can occur.

From this simple idea, a whole series of practical consequences follow. A burning building is the greatest threat to its neighbors at peak burning when the flame area is greatest. The closer neighbor will ignite earlier than the farther neighbor. A large building or a row of buildings burning is a greater threat than a single or small building. Buildings with large window area may pose a greater fire spread threat than one with small or few windows. Combustible walls are a greater threat than masonry walls. Buildings knocked down by the blast wave may burn with smaller flame area and less fire spread than undamaged areas. Very little fire spread by radiation may occur from smouldering debris fires.

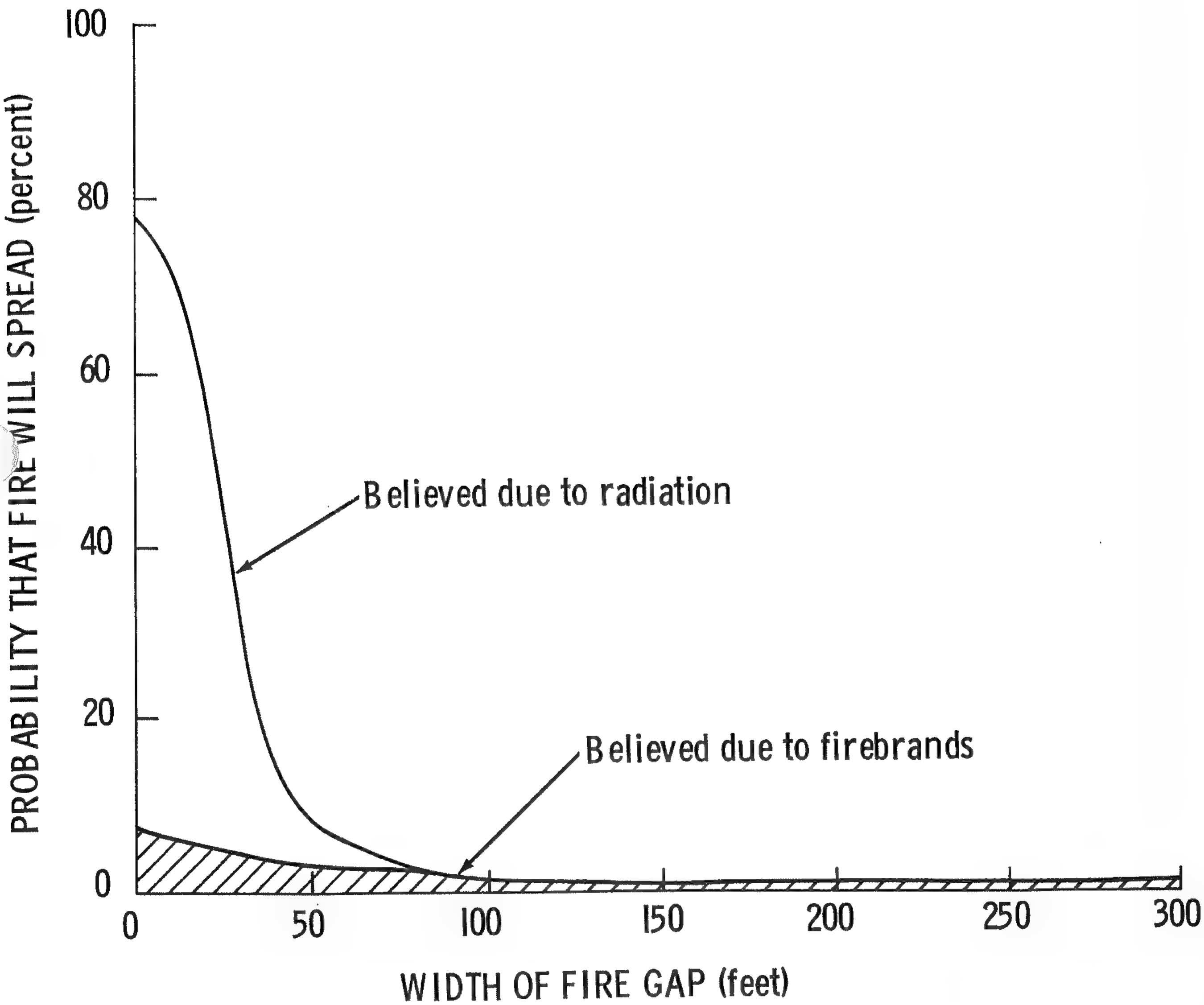
Thus, the curve shown here, which was developed from experience in the World War II fire at Darmstadt in which spread by fire brands was negligible, must be regarded as "average" or "typical." Calculations of radiant energy do indicate that fire spread by this means beyond about 85 feet is most unlikely, even for large windowed buildings. This means that fire can spread between buildings on a block by heat radiation, but generally not from block to block. Detailed surveys of residential areas indicate that the critical "view factor" of 10 percent would be exceeded two times out of three if the house next door were burning, only one time in seven if the house across the backyard were burning, and never if the house across the street were burning.

FIRE SPREAD IN THE DARMSTADT FIRE*



*From Takata and Salzberg, **Development and Application of a Complete Fire-Spread Model**, IITRI, June 1968, AD 684 874.

FIRE SPREAD AT HIROSHIMA*



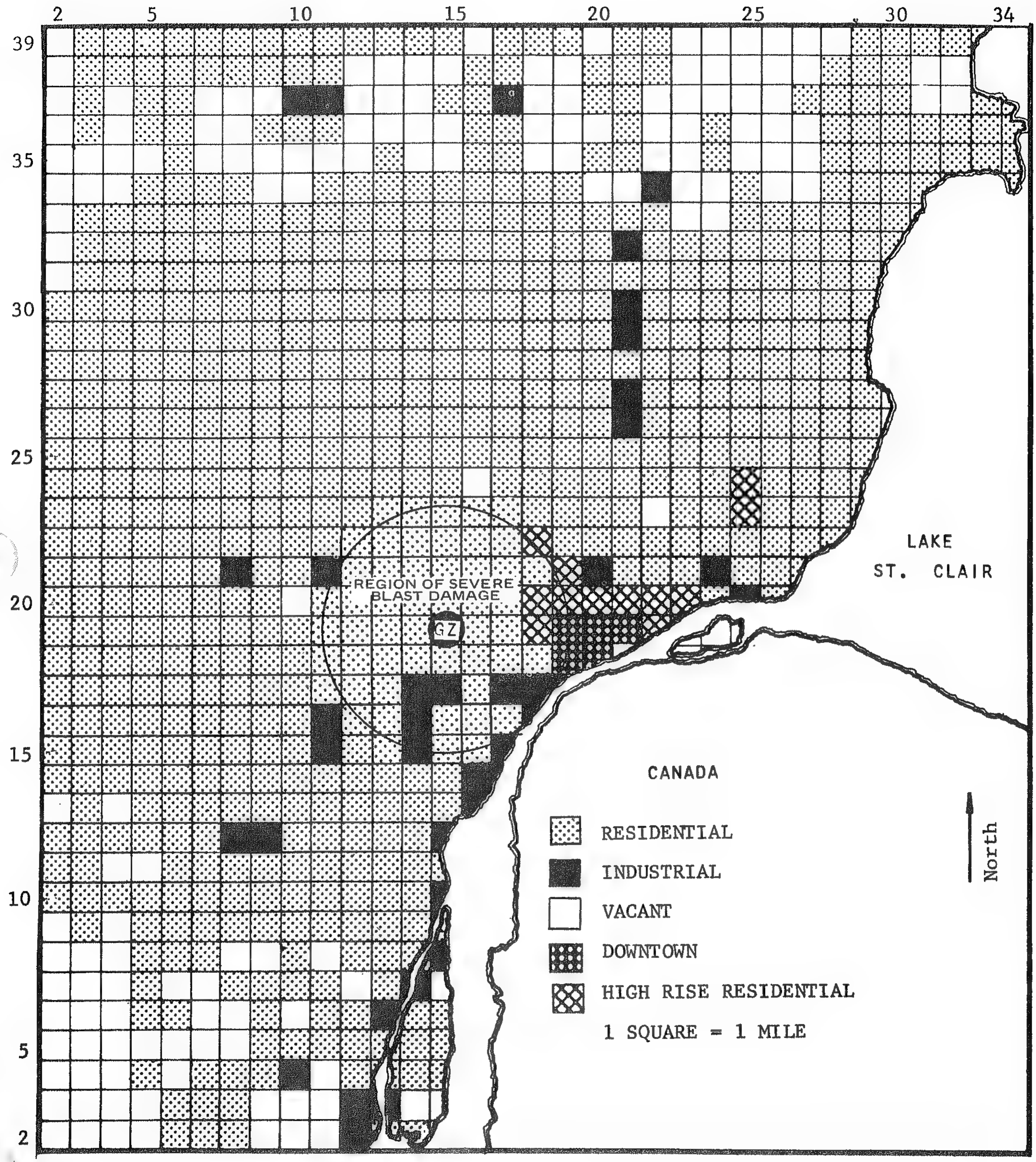
*From Takata and Salzberg, **Development and Application of a Complete Fire-Spread Model**, IITRI, June 1968, AD 684 874.

THE CHARACTER OF URBAN FIRE SPREAD

Fire spread from building to building in urban areas occurs primarily through heat radiation from the flames and through the production of firebrands. As we have seen, spread by radiation is primarily within blocks and block-to-block spread is mainly by firebrands. Fire spread depends on the nature of the buildings and their separation distances.

This map of the Detroit area shows the general character of land use in tracts one mile on a side. Most tracts are residential in nature. The square marked "GZ" marks the ground zero for the 5-MT surface burst for which debris depth contours were given in Chapter 2. You will recall that except within the downtown area, debris depths averaged one-half to one foot over most of the blast area.

A gross description of land use, as shown here, is insufficient to permit estimates of fire spread. The current DCPA fire spread model defines 24 separate tract types within the category "Residential." These range, in Detroit, from Type 1, which consists of all single-story homes having an average base dimension of 30 feet and an overall building density of 15 percent, to Type 24, which consists of apartment buildings—60 percent 3-stories, 20 percent 4 stories, and 20 percent 5-stories—having an average base dimension of 50 feet and an overall building density of 25 percent. This type of information is needed to estimate average "view-factors" for spread by radiation and the likelihood of spread by firebrands.



2
5
10
15
20
25
30
34
39
35
30
25
20
15
10
5
2
REGION OF SEVERE BLAST DAMAGE
GZ
LAKE
ST. CLAIR
CANADA
RESIDENTIAL
INDUSTRIAL
VACANT
DOWNTOWN
HIGH RISE RESIDENTIAL
1 SQUARE = 1 MILE
North

PANEL 23

THE DIMENSIONS OF FIRE SPREAD

To illustrate the overriding importance of fire spread, let us use the example of the 5-MT surface burst at the location shown on the previous panel. For the moment, we will **ignore** two important factors: (1) the **effect of the blast wave on fire ignitions**, and (2) the **effect of any fire countermeasures, either before the attack or after the fires are started.**

For this example, we will assume that all buildings experiencing at least 6 psi blast overpressure are destroyed at the outset. Since most of the buildings with the blast circle shown on Panel 23 are residential or industrial buildings, this assumption is not unrealistic. These immediately destroyed buildings comprise about 14.5 percent of all the buildings in the Detroit area shown on the tract map. Outside the 6-psi line, an additional 3.76 percent of all the buildings are initially ignited.

As can be seen in the table, although less than 4 percent of the undestroyed buildings are initially ignited by the fireball, almost half of the buildings are eventually burned. Together with the nearly 15 percent assumed to be destroyed by blast, almost two-thirds of all buildings are lost by the end of the first day. At 28 hours after detonation, about 1 percent of all buildings are still burning around the periphery of the damaged area, so the destruction shown in the table is not the complete story.

The loss of property due to fire spread dominates the picture, even though a "fire storm" never occurs. Spread by radiation from nearby burning buildings appears to be the most prevalent mechanism, but one should not lose sight of the fact that most of the losses outside the area of high initial ignitions were originated by the firebrands.

We do not know how accurate this picture of the fire spread is, except that it probably represents the upper limit of what might occur without any fire defenses. The reason that it may represent an upper limit is that the effects of the blast wave, ignored here, will generally reduce initial ignitions and may impede fire spread. The main thing that blast effects will provide is additional time to control the fire situation, for even if the initial ignitions do not exceed 10 percent throughout the blast area, these fires can eventually spread as shown here. Thus, if control is not successful in the first few hours, new fires may be set for days following the attack.

Finally, a major implication for operational planning is that mutual aid from nearby localities will have time to play an important role in fire defense.

FIRE SPREAD HISTORY IN DETROIT
(Percent of all buildings ignited and burned*)

TIME (hours)	IGNITED BY FIREBALL	IGNITED BY RADIATION	IGNITED BY FIREBRANDS	TOTAL BURN
0	3.76	—	—	3.76
1	3.76	2.78	—	6.54
3	3.76	8.93	5.50	18.19
10	3.76	17.55	11.50	32.81
28	3.76	28.01	18.16	49.93

* In addition, 14.46 percent of all buildings destroyed by blast, for a total destroyed and burned of 64.39 percent.

From Takata and Salzberg, **Development and Application of a Complete Fire-Spread Model**, Vol. II, IITRI, June 1968, AD 684 874.

LIFE SAFETY IN FIRE AREAS

The traditional fire service priorities are (1) preservation of life, (2) prevention of fire spread to other premises (exposure control), and (3) extinguishment of fires. For peacetime fires, men and equipment are provided to bring to the scenes of fires an overwhelming extinguishment capability, plus salvage and rescue equipment. Any fire company is committed to only one fire at a time, with support available from the remainder of the department and from mutual aid arrangements. Thus, priorities (1) and (2) are almost always achieved, and priority (3) accomplished quite often.

In nuclear attack, unless citizen self-help measures are effective in locating and suppressing smouldering ignitions and firebrands, the first two priorities will represent a challenging task, with priority (1), preservation of life, the controlling requirement.

With respect to life safety, the planner will be concerned with where the people are—in public shelters or in residences in areas where sufficient public shelter is not available. Preservation of this sheltered population is the fundamental goal of emergency operations.

The information in this chapter on fire spread leads to the idea of distinguishing among shelter buildings on the basis of fire risk. For each building or other facility planned for shelter use, the essential question to be asked is: "Assuming that occupants suppress ignitions and fires in the building proper, is the building likely to become untenable from fires in the surrounding area?" Field tests have shown that experienced fire officers have little difficulty in making this judgment. The information in this chapter should assist in any local fire-risk survey.

The upper photograph shows a typical high-risk shelter facility. The lower photograph shows a facility judged to be at low risk from its surroundings.

The implications for planning are:

(1) In areas where surplus shelter exists, community shelter plans should incorporate low-risk shelters in preference to high-risk shelters.

(2) In urban areas where insufficient basement space exists, the basements of high-risk buildings should be used but nearby low-risk buildings should be designated as the relocation sites for the occupants of the high-risk facilities, should one or more become untenable.

TYPICAL HIGH-RISK SHELTER FACILITY

TYPICAL LOW-RISK SHELTER FACILITY

Washingtonian Towers, Gaithersburg, Md., (lower photograph) courtesy of Loewer, Sargent & Associates.

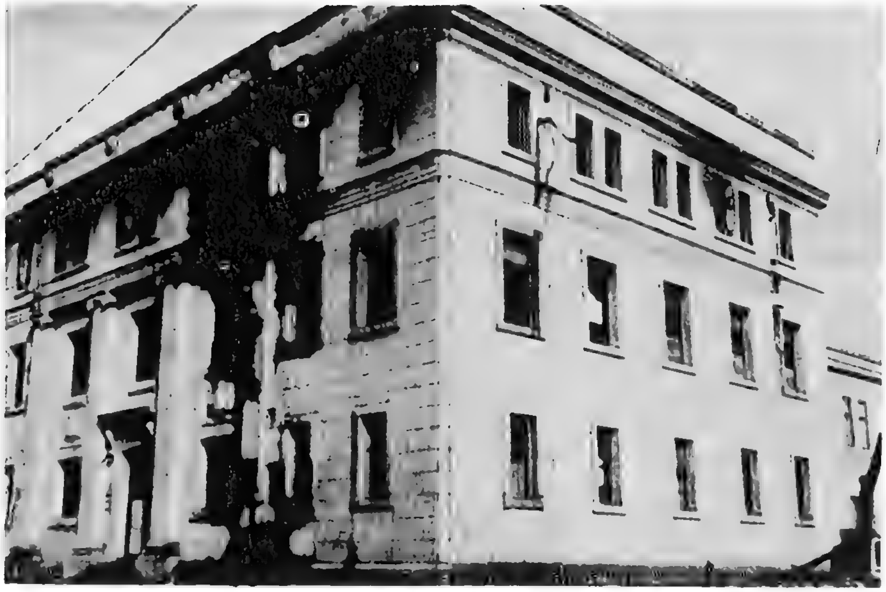
SOME JAPANESE EXPERIENCES

One might question at this point whether it is reasonable to assume that the survivors in a "low-risk" shelter facility can suppress ignitions and fires in an area damaged by a nuclear detonation. The most nearly parallel situation and, hence, best evidence comes from the nuclear attack on Hiroshima at the close of World War II. All of the evidence we have cited in this chapter suggests that the fire situation we must expect would be similar to that experienced at Hiroshima.

The upper photograph shows the Hiroshima branch of the Bank of Japan, a 3-story reinforced-concrete frame building of earthquake-resistant design. This building was only 1300 feet from ground zero, where an overpressure of about 18 psi occurred. About 100 people were in the bank at the time, of which about half were killed. Only four of the survivors are said to have been uninjured. Whether because the detonation was high above the building, whether because there were metal shutters at the windows, or whether because of effects of the blast wave, no initial ignitions occurred. About 1-½ hours afterward, a fire started in a room on the second floor from a firebrand. The nearest burning building was only 25 feet distant but the brand was said to come from nearby burning trees on another side. The survivors extinguished the blaze with water buckets, preventing further damage. A little later, a fire was started on the third floor. It was beyond control when discovered and the third floor burned out. But the fire did not spread to the lower floors.

The lower photograph shows another bank building, farther away, that experienced about 8 psi blast overpressure. Again, no initial ignitions were reported. However, at about 10:30 A.M., over 2 hours after the detonation, firebrands from the south exposure ignited a few pieces of furniture and curtains on the first and third stories. The fires were extinguished with water buckets by the building occupants. Negligible fire damage resulted.

These are but two of several examples of successful fire defense taken from the U.S. Strategic Bombing Survey report of events at Hiroshima. If one assumes that Americans can do what the unsuspecting residents of Hiroshima did, self-help measures by shelter fire-guard teams would appear to be effective.



BANK OF JAPAN BUILDING AFTER ATTACK ON HIROSHIMA

GEIBI BANK CO. BUILDING AFTER ATTACK ON HIROSHIMA

LIFE HAZARDS IN STREETS

Another question is whether it is reasonable to assume that occupants of a threatened high-risk shelter facility can move to a nearby low-risk facility through the damage caused by a nuclear detonation. There is some basis for an answer to this question.

The evidence from Hiroshima indicates that blast survivors, both injured and uninjured, in buildings later consumed by fire were generally able to move to safe areas following the explosion. Of 130 major buildings studied by the U.S. Strategic Bombing Survey (these were hospitals, churches, commercial, and industrial buildings, not the smaller wooden Japanese residences), 107 were ultimately burned out, in total or in part. Of those suffering fire, about 20 percent were burning within the first half hour. The remainder were consumed by fire spread, some as late as 15 hours after the blast. This situation is not unlike the one our computer-based fire spread model described for Detroit (Panel 24).

We have also seen, in Chapter 2, that, except in densely builtup areas of multistory buildings, debris depths will average only a foot or so. This debris would immobilize wheeled vehicles but not pedestrian traffic.

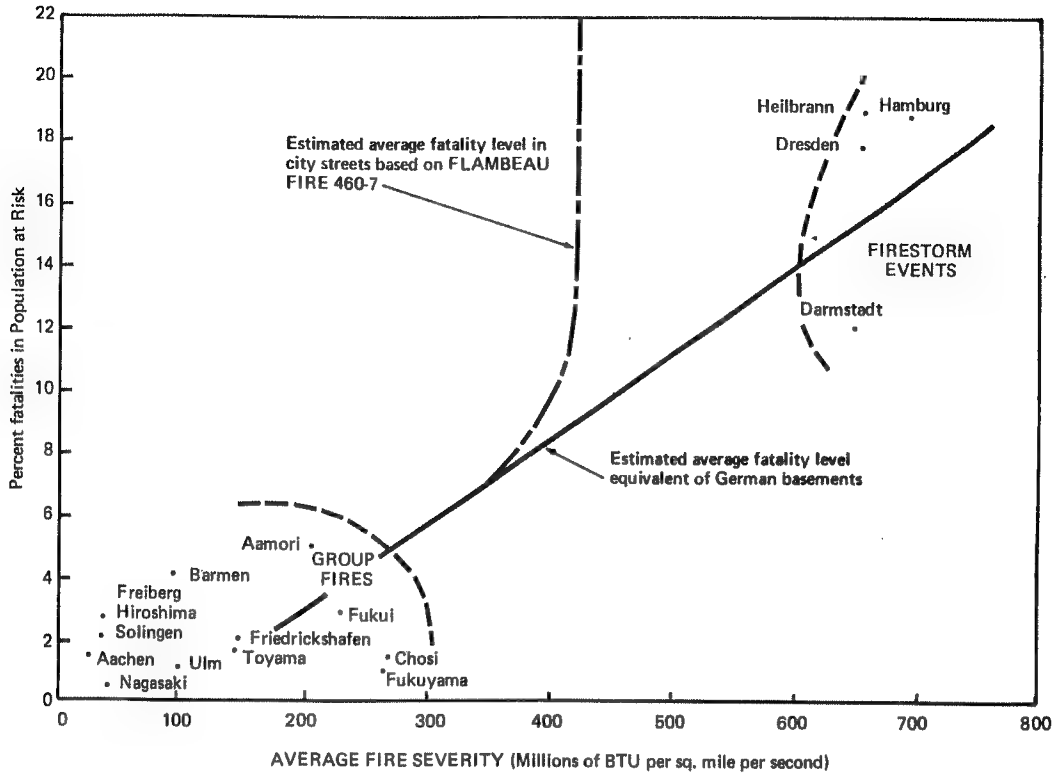
Measurements have been made at the Operation FLAMBEAU mass fire experiments of the hazards to life safety in the streets. It was found that lack of oxygen was not a problem. (Indeed, flames will die out before the air gets too thin for breathing.) Nor was carbon dioxide, a combustion product, found to present a hazard. Heat radiation, elevated air temperatures, carbon monoxide, and lack of visibility due to smoke were found to present a serious threat to life.

The upper chart shows the World War II fatality chart we have seen before, with a line added to show the average fire severity at which mortality in the streets would be expected to become total, based on FLAMBEAU measurements. The table below shows the time period during one of the FLAMBEAU fires when the hazard threshold was exceeded. These fires were intense and the "streets" were only 25 feet wide. Nonetheless, the evidence suggests that there will be situations when people in the streets would be in great peril. These situations will be those in which congested areas with narrow streets are burning violently. The implications for planning are:

(1) Areas where intense conflagrations could occur should be identified in the fire defense plan, and

(2) Decisions to evacuate survivors from these potential conflagration areas should be made as soon as uncontrolled fires are observed, to allow the maximum escape time before radiation intensities, air temperatures, carbon monoxide, and limited street visibility build up to lethal levels.

FATALITIES IN WORLD WAR II FIRES*



* Lommasson and Keller, DC-TN-1058-1, December 1966

HAZARD PERIODS DURING FLAMBEAU 760-12*

HEAT RADIATION	Over 3 Hours
AIR TEMPERATURE	90 Minutes
CARBON MONOXIDE	80 Minutes
STREET VISIBILITY**	60 Minutes

From Butler, C.P., **Operation Flambeau, Civil Defense Experiment and Support,** USNRDL, June 1968, AD 682 476.

** In addition, smoke conditions causing severe eye pain persisted for about 6 hours.

CONFLAGRATION ASSESSMENT

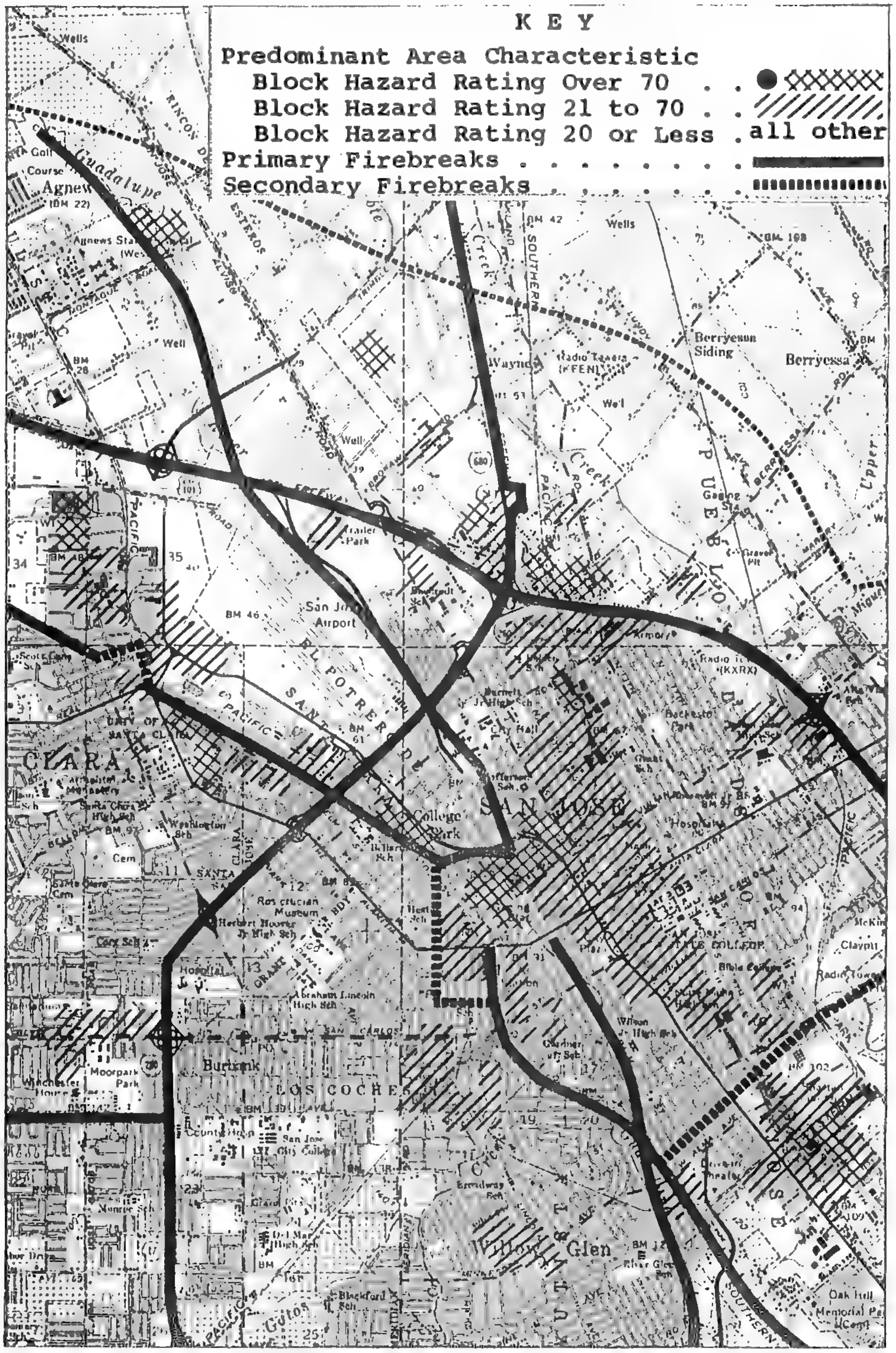
An assessment of the conflagration potential of various tracts in a city will provide a basis for planning fire defense measures, as well as indicating where high-risk shelter facilities should be abandoned as potentially untenable as soon as significant fires are observed in the area. A method has been developed by which such assessment can be made by fire service personnel and others who have a working knowledge of the technology and terminology of fire protection and who are able to identify the various types of building construction. No specialized training is required to use this method, which has been made available as Annex 1 to Appendix E-10-1 of the Federal Civil Defense Guide. The map shown here records the results of an application of the method to a portion of San Jose, California.

The method results in a block hazard rating for each block or group of similar blocks in the city. These ratings, which are based on the fuel loading and builtupness of each block, are meant to represent relative hazard rather than an absolute measure of risk. The higher the block rating, the greater the likelihood of simultaneous burning of many buildings on the block to create a conflagration. Blocks receiving a hazard rating over 70 (the numbers themselves have no physical meaning) are assessed as having a high conflagration potential, shown here as a limited number of cross-hatched areas. Blocks with ratings between 21 and 70 are assessed as having low to moderate conflagration potential but with moderate to high potential for fire spread to adjacent buildings. As we have seen, fire can burn down many buildings, a few at a time, without being considered a conflagration.

A conflagration assessment can form a basis for choice of shelter facilities to be included in the Community Shelter Plan as well as a basis for identifying those tracts that should be abandoned rapidly, should fires occur..

In peacetime, identification of conflagration areas can help in improving assignment of firefighting personnel and equipment. It can contribute to community planning and urban renewal by pointing to existing substandard structures whose razing would reduce peacetime fire hazards in the city. It should also prove useful in planning for emergency operations in natural disasters, such as earthquakes.

CONFLAGRATION ASSESSMENT FOR SAN JOSE*



*From Cohn, B.M., The Conflagation Potential in San Jose and Albuquerque, Gage-Babcock & Assoc., Inc., October 1966

FIRE SURVIVAL IN RESIDENTIAL BASEMENTS

In Chapter 2, it was noted that home basements provide a considerable measure of blast protection. Basements of wood-frame and brick-veneer residences were rated about half-way down the list of best available locations for blast survival. Fire survival in residential basements will require active fire defense on the part of the basement occupants. Only above 5-psi blast overpressure, where the residence is expected to be blown clear of the basement, is fire unlikely to pose a significant threat to the survivors. This situation is shown in the upper illustration.

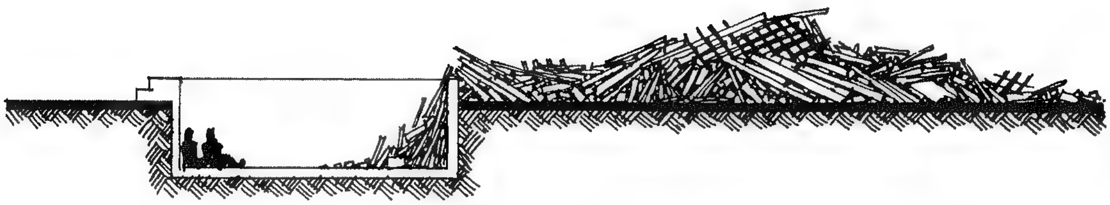
The most serious threat would occur in the moderate damage area at perhaps 2 to 5 psi blast overpressure, shown in the lower illustration. Because residential occupancies are the most vulnerable to fire ignition, basement occupants must search the damaged aboveground portion for smouldering ignitions and secondary fires, should they occur. Secondary fires could be minimized by shutting off the gas and electric utilities prior to attack where they enter the house. Thermal ignitions can also be minimized by preattack closing of blinds and drapes and by dabbing the windows with whitewash, paint, or other opaque materials. Despite these precautions, an immediate search for incipient fires would be necessary.

The blast wind, as we have seen, is likely to delay the development of fire from thermal ignitions for many minutes. The threat of fire from damaged utilities would be the most immediate. Later, the threat of fire spread from neighboring homes may require a fire watch for brands and burning embers. Experiments at the Camp Parks Fire Research Facility have shown that once a fire becomes established beyond the control of self-help firefighting, basement occupants have about 10 minutes to get out of the building, preferably through a basement window, before hazardous amounts of carbon monoxide are likely to be present. The collapse of burning structure would follow shortly thereafter.

It can be seen that, where the best available shelter is in residential basements, there would be significant operational advantages to the grouping of neighboring families in the best basement on the block—best with respect to closeness to other buildings, for example. Most basements will hold 5 to 10 families. Able-bodied people could form fire teams to care for the group more effectively than could each family attempting to cope separately.

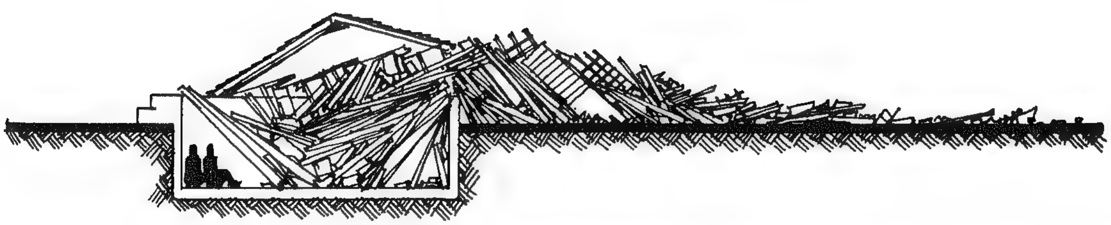
FIRE HAZARDS IN RESIDENTIAL BASEMENTS

over 5 psi



SITUATION OF LEAST FIRE RISK

2 - 5 psi



SITUATION OF GREATEST FIRE RISK

PANEL 29

FIRE RISK IN LARGE BASEMENTS

Shelters in the basements of large buildings, particularly those described as "good shelters" in Chapter 2, offer a substantial degree of protection against fire. An example from Hiroshima, the Fukoku Building, is shown in the upper photograph. This seven-story reinforced-concrete frame building was near the Bank of Japan building and experienced about 20 psi blast overpressure. Subsequently, the building was gutted by fire. Three panels of the ground floor were depressed by the blast but fire did not penetrate into the basement of the building. This failure of the fire to involve the basement was a common occurrence at Hiroshima.

Since the Hiroshima basements were not occupied as shelters, no evidence exists as to whether heat and noxious gases would have prevented survival inside them. There were numerous instances of loss of life in German basements during the "firestorms," mainly due to excessive heat and carbon monoxide poisoning. On the other hand, the majority of basement occupants in these areas survived. To gain a better understanding of the life hazard in basements, experiments have been conducted for the past several years in a reusable building located in Gary, Indiana. This fire-test facility, shown in the lower photograph, has two stories and a basement. The walls are designed to permit openings to simulate varying degrees of blast damage. Combustibles can be placed in one or both stories to represent the room contents for various occupancies—residential, office, commercial, library, and the like. The ground floor slab can be adjusted in thickness and in tightness to simulate openings that might exist.

Experiments to date indicate toxic gases from most debris fires will not penetrate a ventilated shelter sufficiently to cause a substantial hazard. Heat transmitted through the floor slab can present a serious problem, however. For a slab 5 inches thick, which is a common thickness over basements offering "good" blast protection, the heating reaches an equivalent of four added occupants for every shelter space, given a residential fire loading above. The added heat load would make the basements untenable in a matter of an hour or so. An important finding has been that as little as one-third gallon of water per square foot of floor area applied in the first half hour after the start of a fire on the ground floor will reduce the heating effect to about one-quarter of what it would otherwise be. Since broken water piping in the above-ground part of a large building might very well provide such cooling, basements might remain tenable for considerably longer periods than one hour.

Nonetheless, the potential threat of debris fires on the floor above the basement should be guarded against. In addition to possible preattack measures to reduce the fire loading there, "fire guard" teams should be planned for each shelter facility so that incipient fires can be promptly suppressed.

FUKOKU BUILDING FOLLOWING THE HIROSHIMA ATTACK AND FIRE

FIRE ABOVE BASEMENT IN GARY FIRE TEST FACILITY

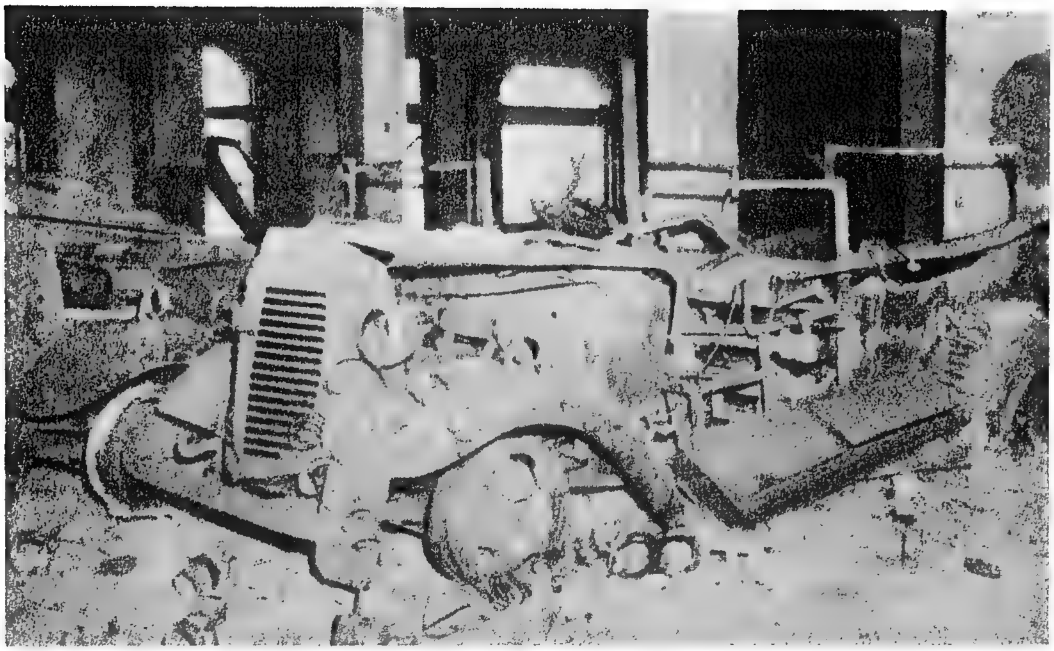
EFFECT OF FIRE ON PROPERTY

Nearly all of the discussion in this chapter has emphasized the saving of life as the objective of fire defense measures. While this is as it should be, the emergency planner should be fully aware of the damaging effects of fire on community resources and productive facilities.

We have seen that fires will occur mainly in the area already damaged by the blast wave. This being the case, one might reach the conclusion that the ensuing fire could add little to the damage that had already occurred. This would be a false conclusion. Blast-damaged equipment, vehicles, and buildings retain much of their original value. Many can be readily repaired and those damaged beyond repair can be salvaged for parts and materials of value in postattack recovery. The consequence of fire, however, is to reduce the salvageable remains to the category of junk, as shown in this photograph.

Studies have shown that important facilities and equipment, such as electric power substations, pumping stations, and the like, must be completely replaced if swept by fire, whereas blast-caused damage can often be quickly repaired. We saw in Chapter 1 that emergency repairs to vital utilities and facilities was a civil defense function spelled out in the law. Prevention of fire damage to vital plants and equipment is essential to the achievement of this objective.

In addition to precautionary measures to minimize fires and fire spread, there appear to be two main planning options available. One is to deploy or maintain professional firefighters and their equipment at critical facilities where their use in fire defense would not depend on the ability to move through the streets. The other would be to locate fire companies at staging areas, together with debris clearing equipment, so that movement to one or more threatened sites might be feasible. Either or a combination of them might be appropriate, depending on the number of critical facilities in the area and the availability of fire equipment and manpower.



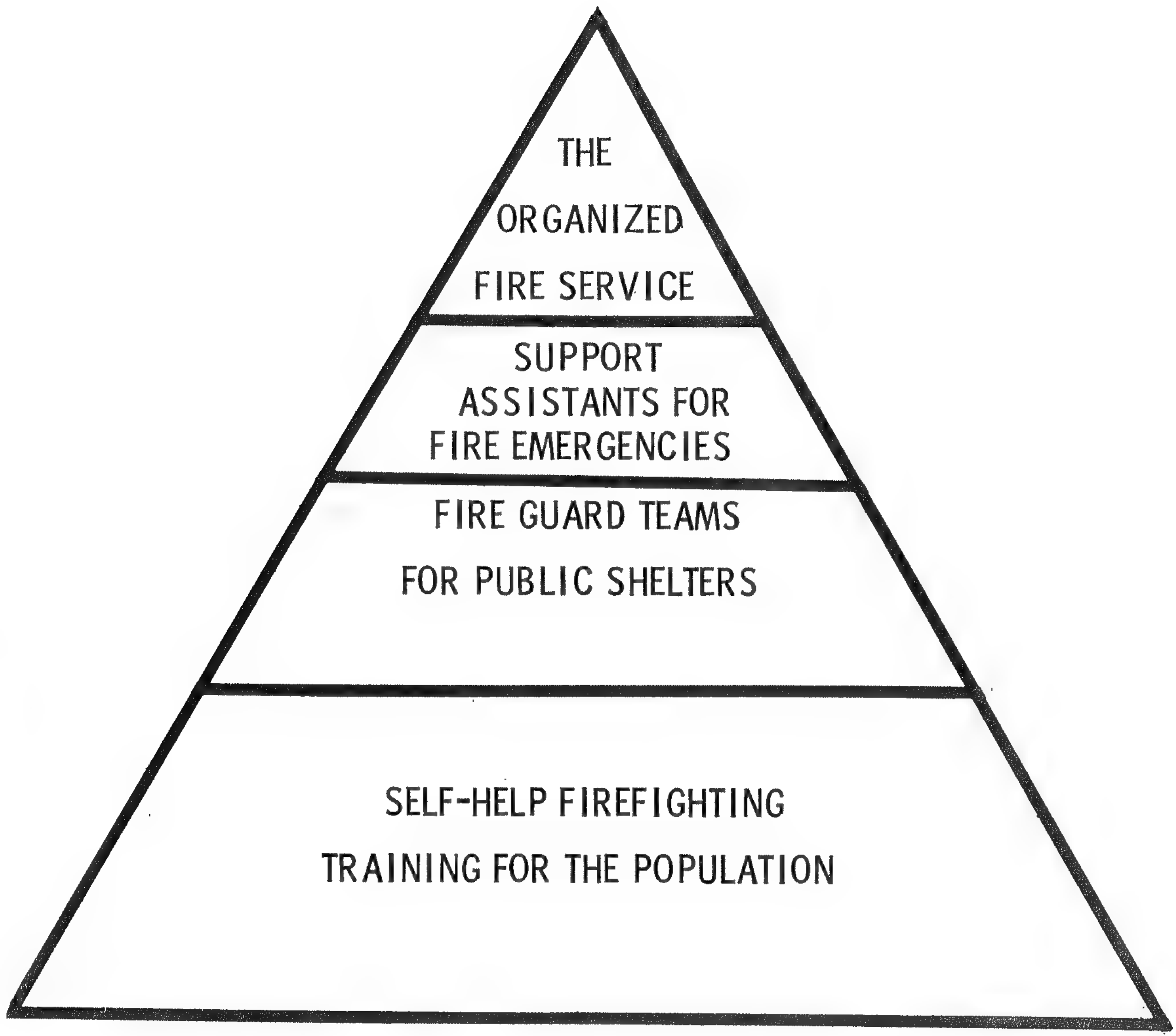
Hiroshima Industrial Company Building showing destruction of fire trucks in public fire department substation in first story. Building was gutted by fire although it suffered only 14 percent superficial blast damage.

THE BASIC FIRE DEFENSE PROBLEM

Whether or not the recent experimental evidence on the effect of the blast wave on thermal ignitions is further substantiated, there would be so many buildings initially on fire that they could not be handled by the professional fire service, even under ideal conditions. In urban areas, there are typically several thousand buildings in each square mile. The average fire company services about two square miles of urban area. Should as few as 1 percent of the buildings be set on fire, each fire company would face 30 to 80 simultaneous building fires. Even near the edge of the fire area, established mutual support arrangements would be insufficient to result in extinguishment of more than a fraction of the fires. When losses of equipment and injuries to personnel, together with probable loss of electric power and water pressure and blast-caused debris blockage of streets are considered, conventional fire defense in the damaged area does not appear feasible.

Clearly, some expanded fire defense capability is necessary if initial fires are not to grow and spread unchecked. A practical fire defense must be based on a knowledge of how unattended fires develop and spread. We have seen that preventive measures prior to attack can have a major impact on the number of ignitions that may occur. We have also seen that undamaged rooms will not flashover until 5 to 20 minutes after ignition. It appears that the blast wave will extinguish flames for periods of 15 minutes to several hours, thus adding to the time available for the application of simple suppression measures.

On the basis of the information at hand, the elements shown in this chart would appear necessary. The professional fire service must assume a broad responsibility for leadership, planning and training, recognizing that in a nuclear emergency the organized fire companies would be restricted to defense of vital facilities and major fire breaks. Fire prevention measures and extinguishment of incipient fires would depend on a broad base of training for self-help emergency firefighting among the population. As specialized parts of a widespread fire defense capability, there is a need for fire guard teams in public shelters, and brigades of trained support personnel (SAFE) to expand the professional cadre.



ELEMENTS OF A FIRE DEFENSE ORGANIZATION

PANEL 32

PUBLIC CAPABILITIES FOR FIRE DEFENSE

In this country, self-help emergency firefighting by householders has been seen mainly in the periodic brush fires that plague central and southern California. This photograph of self-help firefighting is from the Oakland-Berkeley fire of 1970. People such as these have defended their homes from fire without training. The experience of the Forest Service suggests that the effectiveness of householders in fighting fire can be increased about 50 percent by modest training.

The International Association of Fire Chiefs has prepared an intensive 6-hour training course in Self-Help Emergency Firefighting for the Defense Civil Preparedness Agency. The IAFC is prepared to assist by encouraging local fire departments to offer this training in their communities. A reasonable training target, as in Medical Self-Help training, is one trained person in every household.

Citizen fire defense can be effective both in preventing and suppressing fire ignitions. In addition to periodic cleanup campaigns, such as those widely conducted during National Fire Prevention Week, preparations can be made to mobilize the community during a crisis period. Appropriate fire prevention activities in order of priority are:

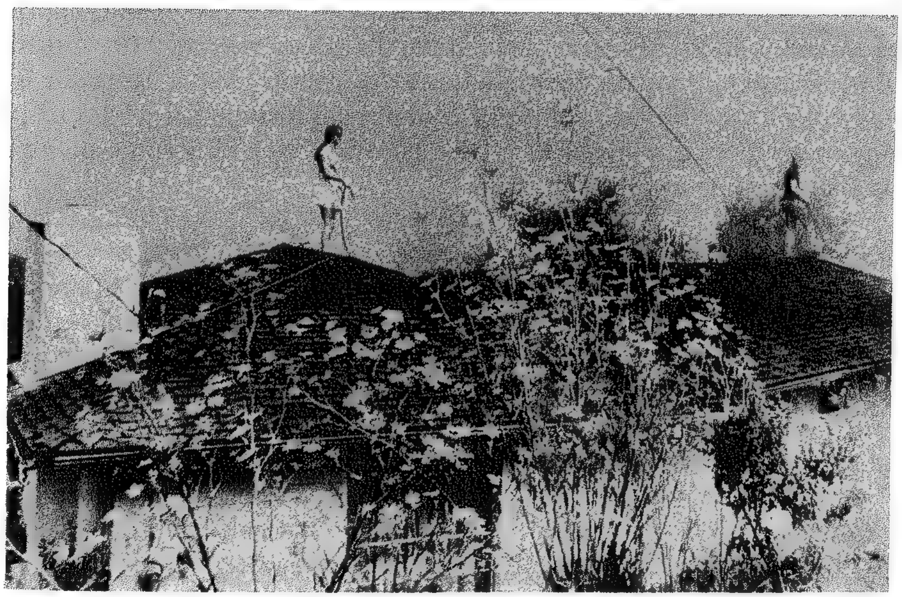
1. Move ignitable items, especially bedding, upholstered furniture, and rugs, to areas that would not be exposed to thermal radiation (about 1 man-hour required).

2. Cover or coat all windows with opaque materials, such as whitewash, paint, flour and water mixture, or aluminum foil (about 3 man-hours required).

3. Clean up garage, basement, and attic, disposing of loose combustible materials (about 1 man-hour required).

4. Clean up trash and ignitable items from exterior of house (about 3 man-hours required).

Extinguishment advice and training should emphasize use of garden hoses, wet mops and blankets, and sand or loose dirt to knock down ignitions to the point where smouldering items can be carried or thrown outside, clear of the house. Experiments conducted by the IIT Research Institute indicate that self-help extinguishment can be near 100 percent effective up to a minute or so before room flashover.



UPI Photo.

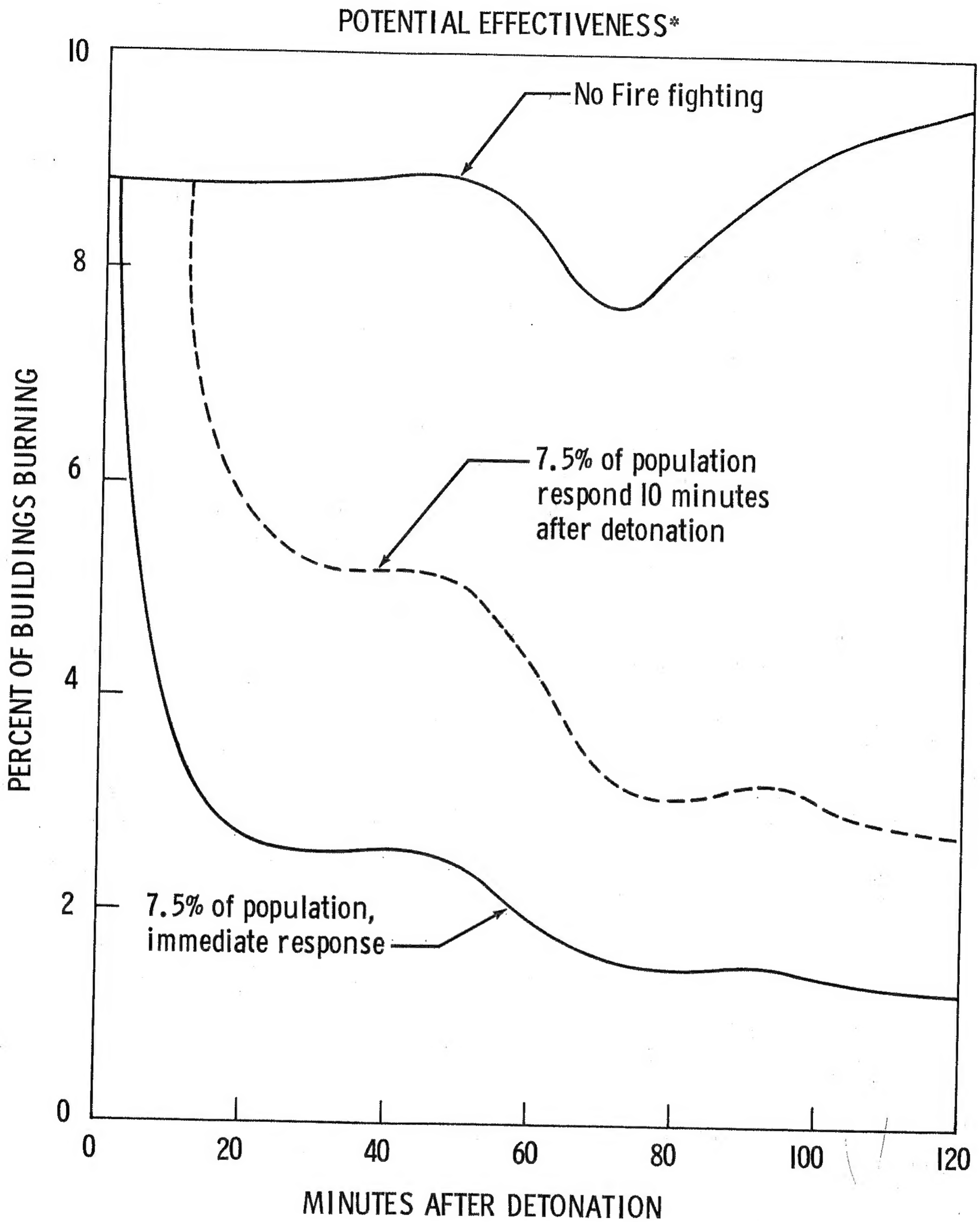
PANEL 33

POTENTIAL EFFECTIVENESS OF FIRE DEFENSES

While the real effectiveness of the sort of fire defenses discussed here cannot be estimated in advance, calculations have been made, using the computer-based fire spread model and some reasonable assumptions on fire defense performance. A typical result is shown here. As you may recall, the fire spread model does not yet include the effects of the blast wave in snuffing out ignitions and delaying room flashover. In addition, no preattack fire prevention measures are assumed.

It is reasonable to assume that at least one able-bodied person is potentially available in each household for firefighting. This would represent a work force of 25 percent of the population. Many of these people would be in public shelters, however. For this example, about 30 percent of the assumed work force is assumed to be available for self-help firefighting in residential areas. The firefighting units are assumed to be of three kinds. First, mechanized fire department units are assumed to be at vital facilities or at staging areas on routes likely to be relatively free of debris. These regular units are augmented by some four-man "brigades" with training similar to the Support Assistants for Fire Emergencies (SAFE) program. Dispersed throughout the residential areas are the self-help units of two men each, supported by SAFE brigades to handle electrical and gas fires and other special problems.

Among the key operating assumptions used in this example were that self-help teams could move from building to building at a speed of 4 miles an hour, that every building had to be searched for ignitions, that search of a residence required 12 seconds, and that one-half minute was needed to suppress each ignition found. It can be seen from the illustration that immediate response by 7.5 percent of the population is very effective in controlling fires and fire spread in the first hour. Once fires start to grow, a delay of as much as 10 minutes can nullify much of this performance. If, however, we introduce the delaying effect of the blast wave, the necessity for "immediate response" is lessened. Nonetheless, the need for prompt and purposive action based on proper training and leadership is evident. Fire defense in a nuclear attack appears feasible but not automatic.



*From Takata, A.N., **Mathematical Modeling of Fire Detenses**, IITRI, March 1970, AD 705 388.

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